7th INTERNATIONAL WORKSHOP ON LASER PHYSICS

(LPHYS'98)

Berlin, Germany

July 6-10, 1998

PROGRAM

AND

BOOK OF ABSTRACTS

Vol. 2

207. WE-Heraeus-Seminar

„Strong-Field Phenomena“

Magnus Haus of the German Physical Society

Dr. Wilhelm Heinrich Heraeus und Else Heraeus-Stiftung

(WE-Heraeus-Stiftung)

7^{th} INTERNATIONAL WORKSHOP ON LASER PHYSICS (LPHYS'98)

ORGANIZED BY:

General Physics Institute, Russian Academy of Sciences
International Journal „Laser Physics"
Max-Born-Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin

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We wish to thank the following sponsors for their contribution to the success of this conference:

- Deutsche Forschungsgemeinschaft
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- United States Air Force Office of Aerospace Research and Development
- WISTA, Wissenschafts- und Wirtschaftsstandort Berlin-Adlershof

Plenary Talks:

Monday, July 6, 9.45-10.30:
P. L. Knight (London, UK): "Strong-Field Manipulation of Atomic Wave Packets"

Tuesday, July 7, 9.00-9.45:
D. Pritchard (Boston, USA): "New Trends in Atom interferometry"

Tuesday, July 7, 9.45-10.00:
E. Wintner (Vienna, Austria): "Diode Pumped Femtosecond Lasers: Limitations and Applications"

Wednesday, July 8, 9.00-9.45:
P. B. Corkum (Ottawa, Canada): "Observing Molecular Dynamics with Timed Coulomb Explosion Imaging"

Wednesday, July 8, 9.45-10.30:
W. H. Lowdermilk (Livermore, USA): "Status of the US National Ignition Facility Project"

Wednesday, July 8, 11.00-11.45:
F. DeMartini (Rome, Italy): "Quantum Optical Techniques for Quantum Information"

Wednesday, July 8, 11.45-12.30:
A. Stratonnikov (Moscow, Russia): " Monitoring of photodynamic reactions in vitro and in vivo"

Thursday, July 9, 9.00-9.45:
W. Demtröder (Kaiserslautern, Germany): "Laser Spectroscopy of Small Molecules"

Thursday, July 9, 9.45-10.30:
M. Raizen (Austin, USA): "Tunneling with Cold Atoms"

Friday. July 10, 9.00-9.45:
E. A. Vinogradov, V. M. Farztdinov, S. A. Kovalenko*, A. L. Dobryakov, Yu. E. Lozovik, Yu. A. Matveets (Moscow, Russia, *Göttingen, Germany)
"Femtosecond dynamics of A^2 B^6 metal microcavity polaritons"

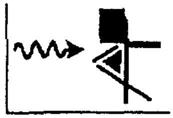
Friday, July 10, 9.45-10.30:
B. H. T. Chai (Orlando, USA): "RGB Color Generation via Self-Frequency Doubling of Nd Doped Yttrium Calcium Oxyborate"

Topics and Scientific Seminars

The workshop consists of the following seminars (organized by the respective cochairs)

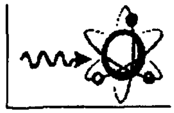
Modern Trends in Laser Physics
(including far IR, X-ray and gamma lasers)

P. Leiderer (Germany)
J. P. Manassah (USA)
K. A. Prokhorov (Russia)



Laser Spectroscopy

S. R. Hartmann (USA)
H. Walther (Germany)
V. M. Yermachenko (Russia)

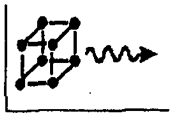


Laser Cooling and Atom Optics

J. Baudon (France)
W. P. Schleich (Germany)
V. P. Yakovlev (Russia)

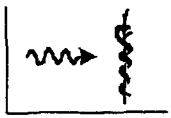
Physics of Solid State Lasers

G. Huber (Germany)
S. Nakai (Japan)
I. A. Shcherbakov (Russia)



Laser Methods in Medicine

S. A. Gonchukov (Russia)
G. Müller (Germany)
R. Steiner (Germany)



207. WE-Heraeus Seminar on "Strong-Field Phenomena"

W. Becker (Germany)
J. H. Eberly (USA)
M. V. Fedorov (Russia)

(*) These times are approximate and may vary from day to day and from seminar to seminar; please, check the detailed program

Rooms:
D1: Radisson hotel, Dom 1; D2: Radisson hotel, Dom 2; R3: Radisson hotel, 3rd room
M: Magnus House, 5 minutes' walk from the Radisson, cp. map

Plenary sessions take place in rooms D1 and D2 merged into one

Conference Schedule

	Monday	Tuesday	Wednesday	Thursday	Friday
9:00-10:30	Opening addresses	D. Pritchard	P.B. Corkum	W. Demtröder	E. Vinogradov
	P.L. Knight	E. Wintner	W.H. Lowdermilk	M. Raizen	B.H.T. Chai
10:30 - 11:00(*)	COFFEE				
11:00 - 12:45(*)	Room: D1 Room: M Room: D2	Room: D2 Room: D1 Room: R3 Room: M	F. DeMartini A. Stratonnikov	Room: D2 Room: D1 Room: R3 Room: M	Room: D1 Room: D2 Room: R3
12:45 - 14:00(*)	LUNCH				
14:00 - 16:15(*)	Room: D1 Room: M Room: D2	Room: D2 Room: D1 Room: R3 Posters 14:00 - 17:30 Room: Lobby	Room: D2 Room: M Room: D1	Room: D2 Room: D1 Room: R3 Room: M	Room: D1 Room: D2 Room: R3
16:15 - 16:45(*)	COFFEE				
16:45 - 18:50(*)	16.45: Departure by bus: Tour of "WISTA Science and Technology Park" Opportunity to visit laser and photonics institutes 19.30: Welcome party (WISTA Photonics Center)	Room: D2 Room: D1 Room: R3	16.45: Departure by bus: Boat trip on Lake Wannsee and the Havel river to Schloss Glienicke Reception and conference dinner at Schloss Glienicke	Room: D2 Room: D1 Room: R3 Room: M	
		17.30 -20:00 Room: R3			

Modern Trends in Laser Physics

Monday, July 6

Chairs: P. Leiderer (Germany) and V. V. Osiko (Russia)

11.00-11.45	C. B. Collins (Dallas, USA) "Quantum Nucleonics for the gamma-ray laser"
11.45-12.15	L. Rivlin (Moscow, Russia) "Gamma-ray lasing - proposals for tomorrow feasible experiments"
12.15-12.45	Yu. E. Losovik, A. L. Dobryakov, V. M. Farztdinov, Yu. A. Matveets, S. P. Merkulova (Troitsk, Russia), S. A. Kovalenko, N. P. Ernsting (Berlin, Germany) "Fermi liquid study in femtosecond scale"
12.45-14.00	Lunch

Chairs: W. Kautek (Germany) and A. Shumovsky (Turkey)

14.00-14.30	V. V. Osiko, T. T. Basiev, Yu. V. Orlovskii (Moscow, Russia) " Growth, crystal chemical structure, and site spectroscopy of MF2 (M= Ca, Sr, Ba) crystals doped with rare earth ions"
14.30-15.00	V. I. Konov, S. A. Uglov (Moscow, Russia), B. Angstenberger, F. Dausinger (Stuttgart, Germany) "Laser induced plasma CVD synthesis of diamond"
15.00-15.25	S. E. Vinogradov, G. G. Kharisov, E. A. Sviridenkov, V. L. Velichanskii (Moscow, Russia) "Intracavity laser spectroscopy with diode lasers"
15.25-15.50	T. F. Morse, E. T. Wetjen (Providence, USA), D. M. Sonnenfroh, M. A. Allen (Andover, USA) "Use of a wavelength modulated Er3+ -Yb3+ doped fiber laser for sensitive detection of acetylene"
15.50-16.15	I. F. Shaikhislamov, V. M. Antonov, S. N. Bagayev, Yu. P. Zakharov, A. G. Ponomarenko, V. G. Posukh, A. V. Melekhov (Novosibirsk, Russia) "A new experimental scheme of charge-transfer pumping of laser-produced plasmas on compact gas cloud for lasing in XUV-range"

Wednesday, July 8

Chairs: C. B. Collins (USA) and V. I. Konov (Russia)

14.00-14.35	A. Shumovsky (Ankara, Turkey) "Polarization of free electromagnetic field and electromagnetic radiation in quantum domain"
14.35-15.00	P. Saari (Tartu, Estonia) "Superluminal localized waves and their relation to tachyons"
15.00-15.25	C. F. Faria, H. Steudel (Berlin, Germany), M. G. A. Paris (Pavia, Italy), A. M. Kamchatnov (Troitsk, Russia), O. Steuernagel (Princeton, USA) "The general solution for non-stationary second harmonic generation with amplitude-modulated incident pulses"
15.25-15.50	A. Nazarkin, M. Wittmann, G. Korn, I. V. Hertel (Berlin, Germany) "Four-wave difference frequency mixing under the condition of coherent two-photon excitation"

Friday, July 10

Chairs: M. Jelinek (Czech Republic) and L. Rivlin (Russia)

11.00-11.30	W. Kautek, J. Krüger (Berlin, Germany) "The Femtosecond-Pulse laser: a new tool for micromachining"
11.30-11.55	S. M. Klimentov, S. V. Garnov, T. V. Kononenko, V. I. Konov, E. N. Loubnin (Moscow, Russia), F. Dausinger (Stuttgart, Germany) "Characterization of plasma and opaque surface layer formation in ceramics ablated by IR and visible picosecond laser radiation"
11.55-12.20	P. Leiderer, M. Mosbacher, J. Boneberg (Konstanz, Germany) "Laser-induced particle removal from silicon wafers"
12.20-12.45	P. Legagneux (Orsay, France) "Excimer laser crystallization of amorphous silicon films with line beam optics"
12.45-14.00	Lunch

Chairs: P. Saari (Estonia) and K. A. Prokhorov (Moscow, Russia)

14.00-14.25	Yu. E. Losovik, S. V. Chekalin, A. I. Ivanov, V. O. Kompanets, D. V. Lisin, Yu. A. Matveets, S. P. Merkulova (Troitsk, Russia) "Femtosecond nanolitography and nanolocal femtosecond study using STM tip"
14.25-14.50	J. Boneberg, H.-I. Münzer, M. Ochmann, M. Tresp, P. Leiderer (Konstanz, Germany) "Nanostructures resulting from the interaction of ns and fs laser pulses with the tip of a scanning tunneling microscope"
14.50-15.15	M. Jelinek, J. Lancok (Prague, Czech Republic) "Nd :YAP and Nd :YAG planar waveguide lasers"
15.15-15.40	P. Hribek, J. Kral, F. Folttiny (Prague, Czech Republic) "Ion-implanted planar waveguide laser structures"

POSTERS: (Poster session on Tuesday afternoon 14.00 - 17.30)

A. I. Artemyev, V. V. Apollonov, M. V.Fedorov, E. A. Shapiro (Moscow, Russia), J. K. McIver (Albuquerque, USA) "Gas-plasma and superlattice free-electron lasers exploiting a medium with periodically modulated refractive index"
K. Reivelt, P. Saari (Tartu, Estonia) "Optical generation of propagation-invariant femtosecond-domain localized wave fields"

Laser Spectroscopy

Tuesday, July 7

Chairs: S.N. Bagayev and T.W. Hänsch

11.00-11.35	H. Walther (Garching, Germany) "Spectroscopy of single trapped ions and applications to frequency standards and cavity quantum electrodynamics"
11.35 - 12.10	Ch.J. Bordé and Ch. Chardonnet (Villetaneuse, France) "Laser spectroscopy test of parity violation in chiral molecules"
12.10 - 12.45	Klaus Müller- Dethlefs (York, UK) "ZEKE - spectroscopy"

lunch break

Chairs: W. Demtröder and E.A. Vinogradov

14.00 - 14.35	V.I. Denisov, S.N. Bagayev, I.I. Korel, V.S. Pivtsov, V.M. Klementyev, S.V. Chepurov and V.F. Zakharyash (Novosibirsk, Russia) "Precise femtosecond spectroscopy of Raman atoms' transition"
14.35 - 15.10	R. Laenen and A. Laubereau (München, Germany) "Generation of sub-ps IR-pulses via parametric processes and application to transient spectroscopy on molecules"
15.10 - 15.45	N.N. Rubtsova, L.S. Vasilenko and E.B. Khvorostov (Novosibirsk, Russia) "Investigation of long-lived states in gases by using coherent transient technique"
15.45 - 16.15	A. Semerok and A. Pailloux (Saclay , France) "Cw laser induced fluorescent spectroscopy of highly magnetized collisionless plasmas"

coffee break

Chairs: Ch.J. Bordé and N.N. Rubtsova

16.45 - 17.10	W.J. Witteman, S.W.A. Gielkens and P.J.M. Peters (Enschede , The Netherlands) "Multi-atmospheric e-beam sustained Ar-Xe laser"
17.10 - 17.35	S. Cavalieri, R. Eramo, L. Fini and M. Materazzi (Firenze, Italy) "Control of photoionization products by quantum interferences"
17.35 - 18.00	J. Robert Huber (Zürich, Switzerland) "Quantum beats in molecules: Creation and manipulation of coherences"
18.00 - 18.25	H. Steudel* and D.J. Kaup** (*Berlin, **Potsdam, Germany) "Coherent propagation in a two - photon absorber"
18.25 - 18.50	R.A. Karle-Shananin, V.N. Petrovskiy, A.V. Panteleev and I.V. Yevseyev (Moscow, Russia) "Intensity resonances at the fundamental frequency of a two-frequency Nd^{3+}:YAG laser with an intracavity nonlinear-absorbing CO_2 cell"

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Chairs: E.V. Baklanov and H. Walther

11.00 - 11.35	S.N. Bagayev (Novosibirsk, Russia) "High - precision laser spectroscopy today and tomorrow"
11.35 - 12.10	I.M. Beterov, V.M. Entin, and I.I. Ryabtsev (Novosibirsk, Russia) "Alignment and orientation in Doppler free spectroscopy of Rubidium"

Lunch

Chairs: I.M. Beterov and W.J. Witteman

14.00 - 14.35	E.V. Baklanov and A.V. Denisov (Novosibirsk, Russia) "Methods of high resolution laser spectroscopy of helium"
14.35 - 15.00	V.N. Petrovskiy, N.V. Naumov, E.D. Protsenko and V.M. Yermachenko (Moscow, Russia) "A double-mode He-Ne and He-Ne/CH4 lasers with synchronized modes"
15.00 - 15.25	S.M. Klimentov, S.V. Garnov, A.S. Epifanov, A.A. Manenkov and D.M. Sagatelian (Moscow, Russia) "Photoelectric registration of multiphoton absorption spectra in wide-band gap crystals"
15.25 - 15.50	V.M. Petnikova, K.V. Rudenko, V.V. Shuvalov and A.N. Zherikhin* (Moscow, *Troitsk, Russia) "Manifestation of ultrathin Ni film ferromagnetism revealed by four-photon picosecond spectroscopy"
15.50 - 16.15	E.V. Pestryakov, V.V. Petrov, V.I. Trunov, A.V. Kirpichnikov, and A.I. Alimpiev (Novosibirsk, Russia) "Spectroscopic and laser properties BeLaAl11O19 single crystals doped with Cr3+ , Ti3+ and Nd3+ ions"

coffee break

Chairs: J. Robert Huber and V.M. Yermachenko

16.45 - 17.15	J.H. Eberly and Ashiqur Rahman (Rochester, USA) "Propagation theory for pairs of short optical pulses: inhomogeneous broadening and area theorems for 3-level media"
17.15 - 17.45	S.R. Hartmann, A.I. Lvovsky and F. Moshary (New York, USA) "Optical superfluorescence transients"

Posters (presented in the poster session on Tuesday, July 7, 14.00 - 17.30):

M. Becucci, S. Cavalieri, R. Eramo, L. Fini and M. Materazzi (Firenze, Italy): "Raman spectroscopy for water temperature sensing"
Shang-Qing Gong , E. Paspalakis and P. L. Knight (London, U.K.): "Spontaneous emission-induced coherent effects in absorption and dispersion of a V-type three level atom"
S.V. Kireev and S.L. Shnyrev (Moscow, Russia): "Collisional relaxation of excited levels of B state in I2 and A2B1 state in NO2 and laser complex for monitoring of molecular iodine isotopes (127I2 and 129I2) and NO2 in atmospheric air"

Laser Cooling and Atom Optics

Tuesday, July 7

Chair: D. Pritchard (Cambridge, USA)

11.00-11.30	**G. Rempe**, S. Dürr, T. Nonn (Konstanz, Germany) "Which-way information in an atom interferometer"
11.30-12.00	**F. Perales**, R. Mathevet, K. Brodsky, K. Rubin, J. Robert, J. Baudon (Paris, France) "Developments in atomic Stern-Gerlach interferometry"
12.00-12.30	**D. Fischer**, S. H. Kienle, W. P. Schleich (Ulm, Germany), V. P. Yakovlev (Moscow, Russia), M. Freyberger (Ulm, Germany) "Quantum state reconstruction of an atomic matter wave"
12.30-13.00	J. Denschlag, D. Cassetari, **J. Schmiedmayer** (Innsbruck, Austria) "Guiding and trapping atoms with a wire"
13.00-14.15	lunch

Chair: R. J. Glauber (Cambridge, USA)

14.15-14.45	**T. Pfau**, H. Gauck, M. Hartl, D. Schneble, J. Mlynek (Konstanz, Germany) "A planar waveguide for atoms"
14.45-15.15	R. J. Dodd (College Park, USA), **C. W. Clark** (Gaithersburg, USA), M. Edwards (Statesboro, USA), K. Burnett (Oxford, UK) "Coherence properties of atom lasers at finite temperature"
15.15-15.45	**K. Vogel**, B. Kneer, W. P. Schleich (Ulm, Germany), T. Wong, D. F. Walls (Auckland, New Zealand) "Generic Model of an atom laser"
15.45-16.15	**V. A. Alekseev** (Moscow, Russia) "Interference of two Bose-Einstein condensates"
16.15-16.45	coffee

Chair: V. Yakovlev (Moscow, Russia)

16.45-17.15	**R. J. Glauber**(Cambridge, USA) Atom counting
17.15-17.45	**E. M. Rasel**, F. Pavone, M. Leduc, C. Cohen-Tannoudji (Paris, France) "New experiments with trapped metastable helium towards high densities"
17.45-18.15	**B. W. Shore**, R. Unanyan, M. Fleischhauer, K. Bergmann "Robust creation of superposition states via stimulated Raman adiabatic passage (STIRAP) with degenerate dark states"
18.15-18.45	**I. Bialynicki-Birula** (Warsaw, Poland) "Squeezed states of matter waves"

Wednesday, July 8

Chair: W. Schleich (Ulm, Germany)

14.15-14.45	**M. Kasevich** (New Haven, USA) "Atom interferometry with cold atoms"
14.45-15.15	**M. Wilkens** (Potsdam, Germany) "Fluctuations in degenerate Bose gases"
15.15-15.45	**K. Rzazewski**, Z. Idziaszek, M. Gajda (Warsaw, Poland) "Fluctuations of the Bose-Einstein condensate"
15.45-16.15	**M. O. Scully** (College Station, USA) "Quantum statistics of an ideal Bose gas cooled by a thermal reservoir or, the laser phase transition analogy and the bosonic ground state"

Thursday, July 9

Chair: J. Baudon (Paris, France)

11.00-11.30	Fam Le Kien (Hirosawa, Japan), **V. I. Balykin** (Troitsk, Russia) "Atom cooling by VSCPT: accumulation plus filtering"
11.30-12.00	**S. Schaufler**, W. P. Schleich (Ulm, Germany), V. P .Yakovlev (Moscow, Russia) "Subrecoil laser cooling with velocity filtering: Measurement of the waiting-time distribution"
12.00-12.30	A. V. Taichenachev, **A. M. Tumaikin**, V. I. Yudin (Novosibirsk, Russia) "Thermodynamics of Bosonic atoms in a dark magneto-optical lattice"
12.30-13.00	R. Schumann, C. Schubert, **U. Eichmann**, R. Jung, G. von Oppen (Berlin, Germany) "Laser cooling of metastable He atoms in electric fields"
13.00-14.15	lunch

Chair: M. Raizen (Austin, USA)

14.15-14.45	**N. Christensen**, H. Ammann, G. Ball, K. Vant (Auckland, New Zealand) "Quantum chaos experiments with laser cooled atoms"
14.45-15.15	**A. R. Kolovsky** (Krasnoyarsk, Russia), H. J. Korsch (Kaiserslautern, Germany) "Chaotic Bragg scattering"
15.15-15.45	**K. A. H. van Leeuwen**, R. M. S. Knops, A. E. A. Koolen, H. C. W. Beijerinck (Eindhoven, The Netherlands) "Design and construction of a high-precision atomic beam machine for quantum optics experiments"
15.45-16.15	V. A. Grinchuk, I. A. Grishina, M. L. Nagaeva, **G. A. Ryabenko**, V. P. Yakovlev (Moscow, Russia) "Dependence of the atomic scattering in the field of counterpropagating light pulses on the mode structure of radiation"
16.15-16.45	coffee

Chair: K. A. H. van Leeuwen (Eindhoven, The Netherlands)

16.45-17.15	**A. M. Ishkhanyan** (Ashtarak, Armenia) "Anomalous coherent scattering of three-level atoms in the strong field of counterpropagating waves"
17.15-17.45	**V. I. Rupasov** (Toronto, Canada and Moscow, Russia) "Quantum nonlinear optics of solids: hidden integrability, confined gap excitations, quantum gap solitons, soliton pinning, etc."
17.45-18.15	**K. Wódkiewicz** (Warsaw, Poland) "Classical and non classical interference in phase space"

Physics of Solid-State Lasers

Thursday, July 9

Chairs: V. Petricevic (USA), I.A.Shcherbakov (Russia)

11.00-11.35	Sadao Nakai, Yasukazu Ilzava, Tatsuhiko Yamanaka, Masanobu Yamanaka, Hiromitsu Kiriyama, Kanji Nishida and Yoshinori Kato (Institute of Laser Engineering, Osaka University, Japan) "Highly Efficient Thermal-Birefringence-Compensated Laser-Diode Pumped Solid-State Laser with High Beam Quality"
11.35-12.10	H. M. Kretschmann, F. Heine, and G. Huber (Institut fur Laser-Physik, Univ. Hamburg, Germany) "Singly resonant sum frequency mixing of two Nd3+ lasers in periodically poled lithium niobate"
12.10-12.45	N. Kugler, T. Brand and I. Schmidt (Laser- und Medizin-Technologie GmbH, Berlin, Germany), C. Gao and H. Weber (Opt. Inst. der Techn. Univ., Berlin. Germany) "Water-cooled Yb:YAG disk laser pumped by a stacked diode array"
12.45-14.00	Lunch

Chairs: G. Huber (Germany), S. Nakai (Japan)

14.00-14.25	N. Il'ichev, A.V. Kir'yanov, and P.P. Pashinin (General Physics Institute, Moscow, Russia) "Low Threshold 100 μs 1.19 μm Operation of a LiF:F2- Laser Pumped by a YAG:Nd3+ Laser"
14.25-14.50	N. Kugler and S. Seidel (Laser- und Medizin-Technologie GmbH, Berlin, Germany) "High Power Nd:YAG Laser with birefringence compensation and adaptive HR-mirror "
14.50-15.15	G.A. Bufetova, D.A. Nikolaev, V.F. Seregin, V.B. Tsvetkov, and I.A. Shcherbakov (Laser Materials and Technology Recearch Center of GPI, Moscow, Russia "Long pulse lasing with Q-switching by FTIR shutter"
15.15-15.40	V. Petricevic (City College, New York, NY, USA) "Laser and Spectroscopic Parameters of Cr4+-Doped Laser Crystals"
15.40-16-05	V.B. Tsvetkov, D.A. Nikolaev, S.Ya. Rusanov, I.A. Shcherbakov, and A.A.Yakovlev (Laser Materials and Technology Recearch Center of GPI, Moscow, Russia) "Lasing in Crystal Fibers"
16.05-16.45	Coffee break

Chairs: N.N. Il'ichev (Russia), Michiyuki Endo (Japan)

16.45-17.10	Wei-Zhu Lin, Yu-Chuan Chen, and Jin-Hui Wen (Dept. of Physics, Zhongshan University, Guangzhou, China) "Novel Modeling for KLM Solid State Laser Resonator"
17.10-17.35	N. Zaitseva, J. Atherton, L. Carman, J. De Yoreo, R. Torres, and M. Yan (LLNL, Livermore, CA , USA) "Rapid Growth of large KDP and DKDP crystals (55-57 cm) for laser fusion applications"
17.35-18.00	A.N. Shelaev (Lomonosov State Univ., Moscow, Russia) "Monolithic solid-state ring lasers with polarization-frequency splitting of the oppositely directed light waves and with polarizationally isotropic resonators"
18.00-18.25	Y.Y. Broslavets and A.A. Fomitchev (Moscow Institute of Physics and Technology, Moscow, Russia) "Investigation of chaotic instabilities in mode-locked tunable Cr4+:YAG laser"

Friday, July 10

Chairs: H. Weber (Germany), Wei-Zhu Lin (China)

11.00-11.35	Michiyuki Endo and Gorachand Ghoshi (Electrotechnical Laboratory, Tsukuba, Japan) "Timing Jitter Reduction of Ultrashort Tunable Pulses using a Mode-Locked Fiber Laser in Soliton Regime"
11.35-12.00	Holger Laabs (Optical Inst., Techn. Univ. Berlin, Germany) "The influence of a local refractive index profile on transverse modes in stable resonators"
12.00-12.25	P.P. Pashinin, E.J. Shklovsky, and V.V. Tumorin (General Physics Institute, Moscow, Russia), C.-Y.Tang (Tamkang University, Tamsui, Republic of China) "Passively Q-switched single-frequency Nd:YAG ring laser with feedback and phase conjugation"
12.25-12.50	V.E. Yashin, V.A. Gorbunov, K.K. Lavrent'ev, and S.A. Chizhov (S.I. Vavilov State Optical Institute, St.Peterburg, Russia) "Nd:YLF-Nd:YAG High peak and average powerlaser system with SBS pulse compression"

POSTER (presented in the poster session on Tuesday, July 7, 14.00-17.30):

Guido Mann and Horst Weber: Measurement of the nonlinear absorption coefficients of KTP crystals in the green spectral range

Laser Methods in Medicine

Monday, July 6

Chairs: G. Mueller (Germany) and A. Priezzhev (Russia)

11.00-11.40	E. Stranadko, O. Skobelkin, V. Meshkov, P. Tolstykh, M. Riabov, N. Markitchev (Moscow, Russia) "Laser in surgery and oncology"
11.40-12.15	H. Weber, M. Frenz, B. Ott, U. Dittli, Th. Carrel, B. Walpott, Th.Schaffner (Bern, Switzerland) "TMLR with 3 different lasers: an in vitro and in vivo study"
12.15-12.45	P. Hribek, J. Panek, H. Jelinkova, V. Kubecek (Prague, Czech Republic) "Ho:YAG and Nd:YAG bile duct stone pulsed laser lithotripsy"
12.45-14.00	Lunch

Chairs: R. Steiner (Germany) and E. Stranadko (Russia)

14.00-14.40	D. H. Sliney (USA) "Limits of localising thermal photocoagulation"
14.40-15.15	W. Grundfest (Los Angeles, USA) "Ablation of biologic tissues using ultraviolet lasers: impact of fluence, repetition rateand environment"
15.15-15.45	A. Stratonnikov, V. Loschenov, V. Polikarpov (Moscow, Russia) "The influence of laser irradiation on photobleaching of endogenous and exogenous fluorochroms and blood oxygen saturation in biological tissues in vivo. The relation to the photodynamics and low intensity therapy"
15.45-16.15	S. Gonchukov, Yu. Lasarev, A. Podkolzin (Moscow, Russia) "Laser refractometry of biological media"

Tuesday, July 7

Chairs: S. Gonchukov (Russia) and D. Sliney (USA)

11.00-11.35	A. Priezzhev (Moscow, Russia) "Laser doppler microscopy of blood flow: state-of-the-art, potential applications, and new approaches"
11.35-12.10	S. Utz, Yu. Sinichkin (Saratov, Russia) "In vivo laser fluorescence spectroscopy in the human skin examination"
12.10-12.45	A. Bednov, E. Zakharova, V. Tuchin, G. Brill, S. Ul'yanov (Saratov, Russia) "Optical monitoring of lymphflow in microvessels"
12.45-14.00	Lunch

Chairs: H. Weber (Switzerland)and P. Plechanov (Russia)

14.00-14.35	H. Schneckenburger (Ulm, Germany) "Laser diagnostic by microscopic methods"
14.35-15.10	G. Mueller, W. Waesche, U. Bindig, K. Liebold (Berlin, Germany) "IR-Spectroscopy for tissue differentiation in the medical field"
15.10-15-45	R. Steiner, A. Rück (Ulm, Germany) "Intracellular mechanisms of photodynamic laser tumor therapy"
15.45-16.15	L. Lademann, H.-J. Weigmann, W. Sterry, A. Roggan, G. Mueller (Berlin, Germany) A. V. Priezzhev, N. N. Firsov (Moscow, Russia) "Investigation of the aggregation and disaggregation properties of erythrocytes by light scattering measurements"
16.15-16.45	Coffee Break
16.45-17.15	K. Doerschel, G. Mueller (Berlin, Germany) "Velocity resolved laser Doppler blood flow measurements in skin"

MODERN TRENDS IN LASER PHYSICS

A new experimental scheme of charge-transfer pumping of laser-produced plasma on compact gas cloud for lasing in XUV-range

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In the late 70-s a charge-transfer pumping of high-Z laser-produced plasmas on neutral gas was proposed [1] and experimentally investigated [2]. An inversion of population for various ions was demonstrated, but the efficiency of the process reached in the experiments was less then 10^{-3} of maximum possible level due to photo-ionization and generation of blast wave which prevents an effective penetration of ions into neutrals. In [3] a way to overcome this obstacle has been suggested. The idea was to use, instead uniform gas atmosphere, a compact neutral cloud created by a low-intensity laser irradiation of a solid target.

In this work the results of the first experimental realization [4] of proposed scheme and the investigation of basic physical aspects of charge-transfer interaction and pumping at high densities are presented. The compact cloud of H/C- neutrals was produced by vaporizing the perlon cylindrical target by a $3\mu s$ impulse of CO_2-laser and was characterized by an exponential profile with the scale $0.25\ cm$ and densities in the range $10^{17}-10^{14}\ cc^{-1}$ on the distances $1-2.5\ cm$ from the target. The flow of C^{+4} ions was generated by irradiation of the planar perlon target by the second CO_2-laser beam of $100\ ns$ duration and $100\ J$ of total energy. The intensity of charge-transfer process between C^{+4} ions and H^o, C^o atoms of cloud was determined by measuring the absolute luminosity in the line $5801\ A$ of $3s-3p$ transition of C^{+3} ion. The instant spatial structure of interaction was obtained by short-time imaging. Also, a flux of VUV-photons in the range $10-50\ eV$ from the interaction region was measured by means of a collector of secondary photo-electrons.

The results obtained showed that the interaction was mainly of charge-transfer character uninfluenced by rival process of electron heating and ionization. The charge-transfer luminosity of C^{+3} ions had a spatial form of a thin ($\prec 1\ cm$) sheath with very sharp boundaries. The absolute intensity of this luminosity points that the interaction with densities $5\cdot 10^{14}\ cc^{-1}$ of ions and $5\cdot 10^{15}\ cc^{-1}$ of atoms has been achieved with effectiveness of charge-transfer pumping $\succ 10\%$. The measured flux of VUV-photons was in agreement with that in the lines of $2p-3d$, $2s-3p$ and $2p-3s$ transitions of C^{+3} ions.

Thus, a practical possibility of charge-transfer pumping at the densities 10^16 1/cc which are necessary for lasing in lithium-like C^{+3} ion has been experimentally demonstrated for the first time. The next logical step, which we plan to carry out in future experiments, is to use a flow of O^{+6} ions so as to pump $4f$ (instead of $3p$) level of O^{+5} ion and to increase the ion flux in the interaction region up to $10^{16}\ cm^{-2}$. A 3-D numerical simulation performed for mentioned above conditions predicts a gain $\succ 1\ cm^{-1}$ on the $\lambda = 520\ A$.

• This work was supported by Russian Fund of Basic Research Grant N 96-02-19074a and National Fund of Basic Metrology

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Nanostructures Resulting from the Interaction of ns and fs Laserpulses with the Tip of a Scanning Tunneling Microscope

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We have investigated the effect of illuminating the tip of a scanning tunneling microscope with single pulses from a frequency doubled Nd:YAG-laser (λ=532nm, FWHM 7ns) or the fundamental of a Ti:sapphire laser (λ=800nm, FWHM 100fs), respectively. For such a system one might expect strong field enhancement near the apex of the tip, giving rise to pronounced nonlinear phenomena. We show the time-resolved response of the tunneling current as function of energy density and distance between tip and surface. Furthermore, we report on surface modifications of the sample below the tip, which show up when the energy density of the laser pulses is sufficiently high. In the case of nanosecond pulses measurements of the transient current increase as well as the transient breakdown of the gap voltage clearly show that a mechanical contact between surface and tip is formed momentarily due to the thermal expansionof the tip. As a result of this contact either hillocks or holes with diameters in the range of 20-30nm can be generated at the surface. Since the material combination of tip and surface appears to be the crucial parameter which determines whether hillocks or holes are produced, we suggest wetting phenomena to be responsible for the details of the formation process. Similar to this observation hillocks can also be formed by femtosecond illumination. In this case, however, additional structures appear in the low energy regime, consisting of clusters of a few nanometers in diameter in an area of several ten nanometers. Altogether, we conclude from our experiments that most of the phenomena observed so far related to structure formation by illuminating an STP tip are due to thermal effects rather than resulting directly from field enhancement.

QUANTUM NUCLEONICS FOR THE GAMMA-RAY LASER

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Abstract Quantum nucleonics is the study for electromagnetic transitions in nuclei that is most analogous to quantum electronics for atoms. It is rich with potential for application. Here particular attention is paid to what it teaches about possibilities for Induced Gamma Emission (IGE) from two and four quasiparticle isomeric nuclei. In such systems excitation of the protons, neutrons, or both give the nuclear analogs of spin-metastable helium atoms. These nuclei can absorb photons to release stored energies of Gigajoules/ gram into freely radiating states that are useful in strategies for a gamma ray laser.

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The movement of charged particles in confined volumes leads to the emission of electromagnetic radiation. Electrons in antennas emit radio waves and microwaves, while electrons moving in molecules and atoms radiate photons of infrared, light, or x-rays. At small scales the motions of charges are quantized and such electromagnetic radiations are emitted as photons during transitions between the discrete levels of energy storage that are allowed in the confined volumes. Within the smaller domain of the nucleus, two types of charges are capable of independent "movement;" the concentrations of positive charge associated with the protons, and the neutron "holes" in the average charge of the nuclear fluid which must act as localizations of relatively negative charge. The transitions between the quantized states of excitation of either (or both) lead to the emission or absorption of electromagnetic radiation known as gamma rays. However, the lowest energies of gamma radiation overlap the highest energies of x-rays and, once emitted; for those energies there is no distinction between photons arising from atoms and those emitted from nuclei.

The same rules of electromagnetic radiation apply to all systems, so in principle, excited states of nuclei could be stimulated to emit their stored energy coherently. A gamma-ray laser would be only the most straightforward result; and analogs of many of the more elegant phenomena of quantum electronics should be expected. Unfortunately. because of the unfamiliar perspectives arising from the strongly interdisciplinary nature of such problems, it is customary to feel that despite abundant evidence to the contrary, nuclei are somehow "shielded" by the electrons and cannot be "seen" by radiation emitted by non-nuclear sources. Originally, results of investigations along the traditional lines of nuclear physics were quite negative in their conclusions, despite the fact they were reporting that ratios of cross sections for resonant nuclear to non-resonant (electronic) interactions of photons with matter actually ranged from 100 to 10,000 across the table of the elements [1]. Nevertheless, from the first proposal for a gamma-ray laser [2] as developed in later reviews [3] it has been clear that an interdisciplinary perspective drawing from quantum electronics, materials science, and nuclear physics could advance the quest for the control of the interactions of photons with nuclei without the need for nuclear reactions involving fission, fusion or energetic material particles.

In all cases the cross section for the interaction of electromagnetic radiation with matter is described by the Breit-Wigner cross section (which is of the order of the square of the wavelength) reduced by effects of recoil, Doppler broadening, and reductions in the lifetimes of the excitation of the material states caused by environmental effects. In the familiar domain of optical frequencies, the latter effects dominate to such an extent that the

actual cross section for the stimulated emission of a photon by Nd ions in YAG is over an order of magnitude smaller than comparable interaction of 14.4 keV photons with Fe-57 nuclei in a foil of iron under Mossbauer conditions which prevent recoil and thermal motion of the nuclei. The electrons in the iron do not shield the nucleus because the peak cross sections for interaction of the electrons with the radiation are greatly reduced by broadening, as in the case of the YAG. While the Mossbauer effect is the most obvious ally in the attempts to control the interaction of photons with nuclear states, there are many others which hold even greater promise.

Even within the quantized structures in the matter interacting with the radiation, there is more similarity between the nuclear and atomic domains than might be first expected. At the simplest level of approximation, in the former the two types of charges move in the spherical oscillator potential, while the electrons move in the Coulomb potential. While this appears to be a major difference, both cases lead to basis state descriptions using somewhat different exponential and hypergeometric functions of radial positions and the same spherical harmonics. Of course, the precise radial distributions and the positions of nodes are different, but in a general view these do not dominate behavior. Electromagnetic transition rules depend upon the angular parts and so the same selection rules result. The important differences arise in more subtle ways. In the Coulomb case, there is an "accidental selection rule in the combination of radial and angular quantum numbers. In the notation of $|NLM\rangle$, this means $(N-L) > 0$. To the contrary, for spherical oscillator bases, 1d, 2f, and even 1h states are perfectly allowable. In contrast to the hydrogenic spacing of atomic levels in energy, for the spherical oscillator, $E = (N+L/2+3/2)h\nu$, where $h\nu$ is of the order of a few MeV. However, the most significant difference arises from the fact that the scale of the nucleus is so much smaller than for atoms. Because of the uncertainty principle, the velocities (and so the magnetic effects) will be much larger in nuclei. This means that spin-orbit coupling will be of dominant importance in nuclear structure. Thus, in "building up" isotopes by filling shells, the addition of an unpaired proton or neutron can add J of up to L+S per particle while exclusion tries to pair the particles with antiparallel J's in the lowest unfilled level. Analogs of atomic metastables such as triplet He can be conceived by "flipping" the J of one member of a pair while promoting it in energy up to the first open level. One such promotion of a proton or neutron produces a two quasiparticle isomer, usually with high J, high energy, and long lifetime; while promotions of both a proton and neutron give four quasiparticle isomers without clear atomic analogs. Examples of the latter, such as the 31-year isomer of Hf-178 store Gigajoules/ gram while still presenting the possibility for ready excitation by photons up to freely radiating states. The high energy densities released have considerable significance to strategies for pumping a gamma-ray laser.

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The general solution for non-stationary second harmonic generation with amplitude-modulated incident pulses

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Abstract

We developed a general method for solving the non-stationary problem of one-dimensional second harmonic generation starting from a purely amplitude-modulated fundamental wave of arbitrary shape.The problem is reduced to the solution of a Schrödinger-type equation, in which the initial pulse-shape is taken as a potential. Several examples with the complete solution given in analytical form are discussed. A much broader class of solutions can be found with the help of one numerical integration. In particular, solutions with incident pulses approximating a sech^2-shape have been obtained. This approach is useful for investigating effects related to group-velocity mismatch in SHG by ultrashort pulses.

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Ion-implanted planar waveguide laser structures

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Great attention of many laboratories concentrates to development of a novel laser amplifiers and oscillators utilising planar or channel integrated-optic waveguides. Such devices are interesting for development of the optical signal generators for soliton fibre transmission lines and for many other integrated optical applications. Merit of such devices is possibility to combine the laser effect with some other phenomena as are electro-optic, acousto-optic, and nonlinear-optic ones, at one small substrate. Low loss, and high gain active optical waveguides are necessary for this purpose.

One possibility how to produce the active optical waveguides is the creation of the planar and the channel optical waveguides in a laser active optical materials (Nd: YAG, Nd:YAP, Nd:LiNbO3, Nd: or Er: doped glasses) by ion implantation.

He^+ or H^+ ion implantation has been used to form a barrier-confined optical waveguides in many different materials, including laser crystals [1, 2]. Up to 3 MeV He' ion beam irradiation with doses 10^{17} ions/cm^2 has been used for waveguide formation, and usually 2% to 5 % refractive index change was observed in substrates [3,4].

We present a theoretical study, design, fabrication, and experimental technique for characterisation of planar active optical waveguides realised by single and double He^+ ion implantation.

The 2.5 MV Van de Graaff accelerator was used for the implantation. The single barrier-confined and double barrier-confined active planar optical waveguides were formed in Nd:YAG crystal substrate by single and double He^+ ion implantation at temperature 77K and the ion energies 2.2MeV and 2.2MeV / 2.0MeV respectively. The doses used were 3x 10^{16} ion/cm^3 for single barrier-confined waveguide and 3x 10^{16}ion/cm^3 / 1x 10^{16}ion/cm^3 for double-barrier confined case, respectively.

A single isosceles prism dark modes method at wavelength of 0.6328µm (He-Ne) and end coupling method has been used for Nd:YAG waveguides characterisation. The refractive index profiles were obtained from experimental dark modes fitting using a Reflectivity Calculation Method (RCM). The analysis showed 5.7µm thick single barrier waveguide with barrier FWHM ~ 0.3µm, and 5µm thick double barrier waveguide with ~ 1µm FWHM.

The profiles obtained were slightly different from those predicted theoretically. Possible explanation of this difference will be discussed.

Two lens (end coupling) method, spectroscopic method, and nonlinear optical method was used for planar waveguide physical parameter measurement (modal field profile, absorption and emission spectrum, and waveguides absorption). The results obtained will be presented and discussed.

Using waveguide laser rate equation analysis we designed and developed 1 mW axially pumped Nd:YAG 5μm x 15 μm x 1.3mm planar waveguide laser. The fundamental parameters such of laser will be presented.

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Laser Deposition of Nd : YAG and Nd : YAP planar waveguides lasers

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The perspective goal of integrated optoelectronics is the development and production of components qualitatively improving the parameters of optical systems and devices. Such components are characterized by small dimension, low weight, high mechanical resistance and high stability and operational reliability.

A source of coherent light easily coupled to the fiber and integrated optics represents an essential component of optical devices. Thus the development of miniature, compact lasers, efficiently generating in visible and near infrared regions, and compatible with fiber and integrated optics, are of great interest from scientific and technological point of view. During the last years diode lasers have become such powerful and efficient small laser sources. Nevertheless the quality of the output beam do not reach the quality of solid state lasers. As it appears, this drawback could be overcome using the active planar and channel waveguide structures as laser generators. This kind of optoelectronic component is widely named planar waveguide (PW) lasers. .

Optical waveguides require a transparent medium in which the refractive index of the layer is higher than that of the surrounding material. Waveguides are based on the principle of total reflection of light from planar dielectric interfaces. The cross-sectional dimensions of the waveguide, together with substrate-film changes of refractive index determine the number of supported modes. The confinement of light in optical waveguides allows a small spot size and hence a high intensity is maintained over length larger than would be normally allowed by diffraction. In such case a high intensity-length product and good pump-signal mode overlap can be achieved with waveguide geometry. Planar waveguides confine the optical wave in one dimension and the optical wave is free to diffract in the other direction what causes the energy losses. Low threshold operation and practical integrated-circuits applications require the confinement of supported wave in both directions perpendicular to the direction of propagation. The waveguides confining the light in both directions are called "channel waveguides". The channel waveguide laser can be also more easily coupled to fiber components than a PW laser.

For creation of planar waveguide structures various techniques such as liquid phase epitaxy, molecular beam epitaxy, metaloorganic chemical vapor deposition, proton exchange, diffusion, ion- implantation, magnetron sputtering and pulsed laser deposition have been used. The most common methods for waveguide production, such as ion exchange and in- diffusion, require a two step process. The ion-implantation is very expensive technique with the need for an ion generator, accelerator, ion separator and a raster scan reflector. The PLD is a very simple, one step method, making possible stoichiometric transfer of target material into thin layer (including dopand concentration) and growth of highly oriented, crystalline layers.

In this contribution our experiences with creation of PW lasers of Ti:sapphire will be shortly mentioned. Focus will be on PLD creation of wavegiuding structures of Nd: YAG and Nd :YAP. Results of XRD, luminescence, stoichiometry mesurement and waveguiding properties will be presented for various deposition conditions. Films with attenuation lower than 1 dB/cm were fabricated.

The Femtosecond-Pulse Laser: a New Tool for Micromachining

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Ultraprecision laser micromachining has excited vivid attention in various industrial fields and in medicine owing to the rapid progress in laser design capable of emitting powerful pulses with durations of less than 1 ps.

In this paper, femtosecond-pulse laser ablation results of the Laboratory for Thin Film Technology of the Federal Institute for Materials Research and Testing, Berlin, since 1992 are reviewed.

Material damage achieved on the targets is determined to a major extent by the heat affected zone (HAZ) adjacent to the surface formed after each laser-induced vaporization pulse. Femtosecond laser treatment leads to HAZ's of the order of ≤100 nm compared to HAZ's in the micrometer range if nanosecond laser pulses are applied [1].

For a wide range of different materials, like metals [1,2,3], semiconductors [1,3,4], ceramics [1], inorganic dielectrics and polymers [5] and for technical [6] and biological composite materials like human corneas [7,8], dental and bone-like materials [1] it could be shown that sub-picosecond-pulse laser ablation leads to enhanced structuring quality. Femtosecond-laser processing avoids any complications by plasma-light interaction (plasma shielding). It provides the possibility to use multi-photon processes which can be of importance for transparent materials. The ablation threshold fluence is reduced substantially compared to nanosecond-laser treatment.

Recent experimental studies of dielectrics for pulse durations down to 20 fs [9,10] and 5 fs [11,12] showed that impact (avalanche) and multiphoton ionization contribute to the ablation process. Multiphoton absorption at lowest pulse durations and high intensities, respectively, yield a maximum electronic energy containment in the irradiated material. It is shown that the ablation depth is reduced below values achieved above 100 fs. The morphology of the ablated areas is controlled mainly by the penetration depth of the laser light in contrast to longer pulses.

These results indicate that a new field of ultraprecision dry etching in micro- and nanotechnology is evolving.

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CHARACTERISATION OF PLASMA AND OPAQUE SURFACE LAYER FORMATION IN CERAMICS ABLATED BY IR AND VISIBLE PICOSECOND LASER RADIATION

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Optical characteristics of plasma and ablated ceramic materials were measured in-situ in integrating sphere experiment employing visible and IR picosecond laser radiation and variety of ambient gases. Observed were: noticeable growth of plasma shielding effect in a deep ablated channel compared to the surface exposure, and formation of a thin (~200 nm) opaque surface layer, which optical and chemical properties were investigated. Estimation of plasma kinetic parameters and comparison the experimental data to ablation rate dependenses allowed partially to attribute the phenomena observed to intense X-ray plume irradiation.

An efficient deposition of energy of laser pulse into a thin surface layer of material is known to be benefit for micro-machining. Ablation of ceramics by IR and visible radiation used not to satisfy this requirement due to their wide initial range of transparency. The present work demonstrates substantial modification of optical characteristics of ceramics exposed to 100 ps pulses of YAG:Nd laser, operating at the wavelengths of 1064 nm and 532 nm, and investigates role of plasma in short pulse laser ablation of transparent materials.

Seeking to trace changes in optical characteristics of plasma at the different stages of the recess formation (from the surface to high aspect ratio ablated well) a variety of integrating sphere experiments was carried out including registration of shot to shot evolution in transmission and reflection of plasma plume and of the ablated material itself in a particular spot on the surface of AlN and Al_2O_3 ceramics, ablated in the intensity range of $10^{10} \div 10^{12}$. W/cm^2 in vacuum and air ambient atmosphere. After that, the chemical composition in the exposed area and the depth of modified stratum were examined it Auger spectroscopy experiment, the corresponding extinction coefficients were estimated and the data obtained were checked against morphology of the ablated craters and etch rate dependences, measured under the same experimental

conditions [1]. The transmission parameters were registered both: for sub-threshold power densities, which enabled measurements of initial and modified optical characteristics of the material itself; and for several levels of ablating intensities to evaluate surface plasma transmission.

As it was shown from transmission and Auger experiments, only few laser shots (1÷2) at the intensity level of 10^{12} W/cm^2 were necessary to build up in AlN ceramics a thin (~100÷300 nm) surface layer blocking more than 80% of incident radiation. Reflection measurement did not demonstrate any shot to shot growth, so the observed decrease of transmission could be ascribed to absorption in the modified material. Calculations performed for IR and visible radiation of the equal intensity gave the integral absorption coefficient of the surface layer between $95{\cdot}10^3$ and $115{\cdot}10^3$ cm^{-1}, demonstrating weak spectral dependence of this parameter. The obscuring effect showed sharp intensity dependence and was not observed in ablation and transmission tests with longer pulsewidths.

Parameters of surface plasma in the ablation process were estimated for the case of Al_2O_3 ceramic demonstrating no material modification in the available intensity range. Taking into account the measured transmission and reflection of the plume and experimental data [2] gave electron temperature of 150÷350 eV and concentration of ~10^{22} cm^{-3}. The calculated power of plasma irradiation amounted in our case to 25÷40% of the absorbed incident power of laser radiation, while the spectral peak corresponded to the wavelength range 0.7 ÷ 1.5 nm. It should be stressed, that the extinction coefficients for X-rays in the compounds of interest should belong to 0.1÷1.0 μm^{-1} range [5], which exceeds sufficiently absorption at the laser wavelength. The observed in experiment noticeable growth of laser radiation shielding and following ablation rate decrease in a deep crater was partially attributed to evaporation of material from the side walls by plasma plume emission and this way to elevation of the resulting vapour pressure near the surface.

The obtained experimental data on plasma plume optical characteristics and estimations of spectral range and power of re-emitted radiation indicated possible substantial role of X-ray plasma irradiation in the ablation process in the initially transparent solids including modification of their optical properties due to radiation defect formation. The present research was supported by grant #97-02-17675 of Russian Federation Fund for Basic Research .

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Laser induced plasma CVD synthesis of diamond

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Diamond films, deposited by plasma CVD technique and exhibiting a set of unique properties, are intensively investigated in the last decade. Different plasma sources, such as MW, RF and electrical discharges, can be used for diamond synthesis. One of the problems in many applications of plasma produced diamond (as well as a number of other hard coating materials) is the necessity to use vacuum chambers because most of conventional plasma reactors operate at gas pressures $p \leq 0{,}1$ atm.

We propose a new approach to CVD diamond synthesis based on utilization of optical discharge in a atmospheric pressure gas mixture steam. This method opens the possibility to deposit diamond and other materials directly in the air if diffusion of air molecules to a substrate surface is prevented. Principally, the proposed technique is similar to dc arc-jet and can be called laser plasmatron.

Stationary optical plasmatrons, considered in this work, have a number of specific features that make them different and advantageous over other of plasma reactors. First, with conventional high power ($P \geq 1.5$-2 kW) CW CO_2 laser plasmas can be produced in practically all gases of interest at $p \geq 1$ atm. More over, in the region of $1 \leq p \leq 10$ atm the maintenance of a stationary gas optical discharge is easier for higher pressures. Second, high concentration of gas molecules combined with record power density that can be released in the gas optical discharge by focused laser beam (up to 10^6 W/cm^3 and even more) can result in the extreme deposition rates. Besides, such plasmas have temperature ($\geq$ 15.000-20.000 K), more than for conventional plasma devices, and is a powerful source of UV radiation that can activate the substrate surface. Third, laser induced plasma CVD process is clean because do not demand electrodes.

It should be noted that although laser plasmatrons have been known since 60-s (see, e.g. books [1,2]), most of the activities in this area were focused on investigation of plasma itself. Only a few experiments performed with pulsed lasers demonstrated possibility to apply laser produced gas breakdown plasmas for CVD synthesis of materials.

The most important result obtained is the deposition of polycrystalline diamond films in the proposed chemical reactor. Substrate temperature was varied in the range 400-1300^{0}C. Deposition area increases with laser power from about 1 cm^2 to 10 cm^2 for 1.5-2 kW to 6-8 kW, correspondingly.

Deposition rate of diamond films depends strongly on: substrate surface temperature, T; methane concentration in hydrogen, C, that was varied from C=1% to 30%; (H_2+CH_4)/(Ar or Xe) gas mixture ratio, N, (changed from N=5% to 25%), and distance, L, between the plasma core and substrate surface. Good quality polycrystalline diamond films were deposited in the temperature range of 700°C - 1250°C and at methane concentration C=1-4%. The highest deposition rate of diamond films observed until now was 40 μm/hour for diamond film which was produced under following conditions: substrate temperature T=1150°C, gas mixture ratio Ar:H_2:CH_4 = 270:25:1, laser power 1,6 kW, distance L=1,7 cm. For lower T values the slide, hard, and transparent nanocrystalline diamond films were also synthesized in the regions of T = 450°C - 650°C and C = 4% - 30%. On the other hand from our observations, the laser power and summary gas mixture flow influence slightly on diamond deposition rate.

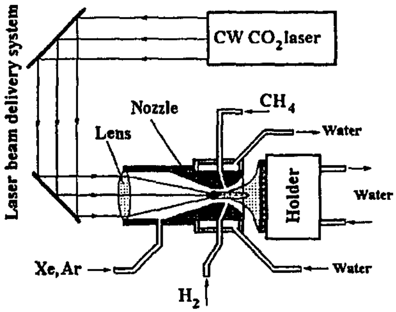

Fig.1. Principal scheme of experimental set-up.

Raman spectroscopy, electronic and optical microscopies were used for analysis of deposited film.

In conclusion, we would like to emphases that the developed deposition technique could be used for CVD synthesis of various materials, for example nitrides.

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EXCIMER LASER CRYSTALLIZATION OF AMORPHOUS SILICON FILMS WITH LINE BEAM OPTICS

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Pulsed laser crystallization of amorphous silicon films deposited on large size (up to $1m^2$) glass substrates appears to be the best method in order to fabricate active matrix liquid crystal displays with integrated drivers, using the low temperature polysilicon (LTPS) technology. One of the main problems, associated with the industrialization of this technology, is the non uniformity of the TFT performances. This non uniformity induces a degradation of picture image quality but also of the characteristics of the integrated driver circuits. In fact, the TFTs performances are directly related to the crystalline quality of the active polysilicon layer which depends mainly on the distribution of the grain size among the glass plate but also on the surface roughness of the crystallized films.

In this paper, we present the various mechanisms responsible for this non uniformity.

After a recall of the various crystal growth regimes that can follow the melting of thin layers of silicon, we will present the associated microstructures (average grain size and surface roughness) of the crystallized films after irradiation with a XeCl (λ=308 nm) laser operated, at a fixed position, using 1 to 10 shots, under various atmospheres. In particular, in order to obtain large grain polysilicon material, we have measured a width of +/- 3 % for the processing window of the laser energy density. The same kind of window width is therefore required for the pulse to pulse stability of the laser if non uniformities are to be avoided.

Furthermore, we will show that the energy density of the first shot is of prime importance for the evolution of the microstructure and crystalline quality of the polysilicon material upon subsequent meltings (up to 10 shots). This evolution of the microstructure is particularly important for scanning conditions (which are needed for the crystallization of large area a-Si films) because at the leading edge of the laser beam, there is always an energy gradient which induces a variety of grain sizes. There is then a memory effect upon remelting because the irradiation conditions are optimized for the amorphous material and not for the crystalline one. This phenomenon is another source of non uniformities in crystallite sizes.

Laser-induced Particle Removal from Silicon Wafers

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The continuing trend towards miniaturization of integrated circuits requires increasing efforts and new concepts to clean wafer surfaces from dust particles. We report here about our studies of the "laser steam cleaning" process first described by Tam and coworkers (1). In order to remove submicron particles from a surface, first a thin liquid layer is condensed onto the substrate from the gas phase, and is subsequently evaporated momentarily by irradiating the surface with a short laser pulse. We have investigated the nucleation and growth of gas bubbles in the liquid, by which the whole process is started, with optical techniques using light scattering, reflectivity and, for very sensitive measurement in the very early stages of nucleation, surface plasmon resonance spectroscopy. The latter method was also used for monitoring the pressure wave generated when gas bubbles are formed. The experiments indicate that the temperature where nucleation sets in is surprisingly low, which facilitates the application of this phenomenon for cleaning purposes. On the basis of these results and in order to study the cleaning effect for the particularly interesting surface of silicon in a quantitative way, we have deposited well-characterized spherical polymer and silica particles of different diameters from several ten to hundred nanometers on commercial Si wafers and have studied systematically the cleaning efficiency of the explosive evaporation process. The laser source used in these experiments was a frequency-doubled Nd:YAG (λ=532 nm with 7 ns pulse width. We find a well-defined threshold for the light-induced removal of the particles at a laser intensity close to 100 mJ/cm^2, irrespective of the size and chemical composition of the particles. This demonstrates that the explosive evaporation of the liquid film dominates the particle ablation process. The observed threshold is about a factor of 3 below the energy density where the silicon surface starts to melt, which provides a sufficiently large energy window for detaching particles without damaging the wafer. By contrast, the threshold for removing the same sort of particles by dry laser cleaning(i.e. without condensing a liquid film just before the application of the laser pulse) was close to the damage threshold of the silicon surface, which renders this metod insuitable for the present cleaning purposes. Laser steam cleaning, however, appears as a promising technique for removing sub-micron dust particles from silicon wafers.

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Femtosecond nanolitography and nanolocal femtosecond study using STM tip

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The nanolithography technique is proposed and realized experementally using the local field of femtosecond laser pulses enhanced in a submicron region due to lighting rod effect or to the excitation of local resonances in STM tip - substrate system. Surface topography analysis in STM mode demonstrates the controlled surface modification in a suitable regime of intensity parameters and femtosecond laser pulses focusing in the STM tip region.

The problems of creation of nanostructures, ultrahigh density recording of information, investigation and recording of ultrafast processes in nanostructures as well as finding of suitable materials and techniques for these purposes belong to the most actual basic and applied problems.

Nanolocal research of influence of ultrashort laser pulses on the solid state surface is of interest from this point of view [1]. We used here the proposal [1] of using local electromagnetic fields enhanced in submicron region near STM tip due to the lighting rod effect or the excitation of local resonances (see, e.g.[2]) in small regions of the STM tip - substrate system for nanolithography and nanolocal research of ultrafast processes [1]. Using of ultrashort laser pulses for nanolocal studies has the following advantages. Femtosecond laser radiation allows to create non-stationary states of sample, which may lead to new *non-thermal* mechanisms of instability and photoinduced phase transitions on the surface. One of the phenomena of this kind is a specific femtosecond melting of solids (another example is appearance of the photoinduced by femtosecond laser irradiation quasi-one-dimensional surface relief with period ~1000 Å see [1] and Refs. herein). Moreover, femtosecond radiation allows realization of peak surerstrong fields without non-controlled destruction of the sample.

The surface of the sample was irradiated by femtosecond laser radiation focused in the region of STM tunnel junction. The radiation of Ti:Sa laser with wavelengths 812 and 406 nm, pulse duration 40-45 fs and repetition rate 82 MHz was used. The radiation power W was changed by means of light filters with different transmittance up to the maximal power 80-100 mW on wavelength 812 nm. The maximal power of 2nd harmonics (406 nm) was $5 \div 7$ mW. The diameter of light spot on the surface was about 1 mm. The dependence of radiation effects on exposition time was also investigated in wide range of exposition times. The angle of incidence ϑ of laser light

was limited by the construction of the setup : $\vartheta \geq 76^{\circ}$. The pyrolithic graphite as a sample was used.

We investigated the possibility of nanolocal laser pulse induced modification of the sample surface in the region nearly the STM tip. At the beginning we obtained the several initial images of surface by STM, reproducibility of images was checked and a lateral drift was estimated. Then we "draw" by laser pulses nearly STM tip one of the figures: point, line or X-like "letter" by means of positioning STM tip in appropriate points and switching on the laser light. So the lines were drawn as a set of separate points. After laser pulse exposition of STM tip we take a duplicate scan of affected region to find photoinduced surface changes.

Laser irradiation effect on STM response *during* the *continuous* scanning process in STM was also studied. At first we take the initial scan, then we take the duplicate scan of the same region when the laser light of different intensities illuminated the tunnel junction. After that we take another scan without laser irradiation.

The experiments revealed the following effects:

1) The appearance of X-like structure after drawing the letter "X" by the local laser field nearly STM tip by means of positioning STM tip in appropriate points and exposition by the laser pulses with power 6.8-8.5 mW. The whole size of long-life X-like structure was 2000×8000 Å with line thickness of the order $\sim$1000 Å and 15 Å depth.

2) The appearance of short-lifetime groove with 200 Å width and 50 Å depth due to writing by the tip and simultaneous femtosecond laser irrradiation with power 6.8-8.5 mW. It should be noticed also that the groove has continuous form unstead of consisting of the sequence of points. It is possible this feature is due to a neglegible change of value of the local electromagnetic field on the surface due to the small tip displacement.

The appearance of long-lifetime structure after the nanolocal affecting of femtosecond laser radiation demonstrates promising of nanolithography method discussed in the paper. It could be intresting to study the direct influence of laser radiation on the STM tip, tunneling and photoemission from the tip. The field enhanced in a local region near STM tip can be also used for the purposes of controlling of nanolocal chemical reactions provided by special STM tip [3] and also for the stimulation of nanolocal photochemical reactions [1]. The work was supported by INTAS, Russian Foundation of Basic Research and Program "Fundamental spectroscopy".

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Fermi liquid study in femtosecond scale

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The new method of investigation of Fermi surface and Fermi liquid (FL) versus non-Fermi liquid (NFL) behavior in strongly correlated electron systems by femtosecond laser spectroscopy is proposed and is demonstrated on superconductor $YBa_2Cu_3O_{7-\delta}$ and for comparison on Au and Cu metals.

The new method of investigation of Fermi surface and Fermi liquid (FL) versus non-Fermi liquid (NFL) behavior in strongly correlated electron systems by femtosecond laser spectroscopy is proposed. The method consists in detailed study of spectral dependence of the nonequilibrium charge carriers relaxation time by pump-supercontinuum probe technique. The method is demonstrated on high Tc oxide-superconductor $YBa_2Cu_3O_{7-\delta}$ and metals Au and Cu by studying the temporary changes of optical density of corresponding thin film in wide spectral region of probing $\hbar\omega_{probe} = 1.6 - 3.0eV$. The relaxation time sharply grows in the spectral area, related to optical transitions into the vicinity of Fermi level (or its shadow if the strongly correlated electron system forms marginal liquid) due to reduction of phase space volume of final states. The specified fact determines an opportunity of the introduction of quasiparticles for the FL, the attenuation of which sharply drops near to a FS.

The found out dependence opens an opportunity for a new method of determination of the Fermi level position and establishment of its existence in a system of strongly-correlated electrons. Moreover the form of peak gives unique information on the damping rate of quasiparticles near FS and thus on the FL vs. NFL behavior. Due to essential growth of the relaxation time to very close the Fermi level the quasiparticles in this region are nonequilibrium subsystem. The form of this spectral dependence of relaxation rate gives unique information on the damping rate near Fermi level and on deviation of thermalization of nonequilibrium electron

from quasiequilibrium electron subsystem.

The excitation was executed by optical pulses with a duration $50fs$ and intensity $2.4 \times 10^{11} W/cm^2$ with energy of photon $\hbar\omega_{pump} = 2.34eV$. The diameter of an excitation spot was $250\mu m$. The reflectivity was investigated with the help of a supercontinuum probing pulse with duration of $50fs$ in a range $1.6 - 3.0eV$. The diameter of a probing spot was evaluated as $150\mu m$. The repetition frequency of excitation and probing pulses made $1Hz$. The delay variation step was $7fs$. The maximum delay reached $\tau \sim 4ps$.

It was found out, that τ_1 essentially depends on a wavelength of a probing: its value for YBCO is equal to $\tau_1 \simeq 300 \pm 60fs$ in the region $1.7 \leq \hbar\omega \leq 2.0eV$, grows up to a maximum $\tau \sim 1.8ps$ at $\hbar\omega \sim 2.06eV$ and have the value $250 \pm 150fs$ in the region $2.1 \leq \hbar\omega \leq 3.0eV$. It is shown that femtosecond optical response of Au and Cu films are dominated by the delayed thermalization of the electron gas with essential nonequilibrium behavior near to Fermi level. Moreover we find relaxation rates connected with electron-electron and electron-phonon scattering rates, respectively. At the energies hw=2.45 eV corresponding to transitions from d-band near the L point of the Brillouin zone to the Fermi level the slowing down of relaxation rate with prominent minimum at 2.45 eV is clearly observed. The analogeos peak in Cu is observed.The forms of peak in Au and Cu are consistent with FL behavior. For YBCO some deviation from FL behavior can present.
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Inversionless super-radiance from assemblies of three level atoms

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Dicke [1] developed the theory of super-radiance (SR) for a system made up of two-level atoms. It is well-known that one of the necessary conditions for this effect to be realized is existence of population inversion between levels involved in the emission process.

In the last decade, the problem of amplification and lasing without inversion (AWI and LWI) is widely discussed [2-4]. Such a possibility appears if one includes into consideration a third operating level, for instance, close to the ground one (Λ-scheme), and prepares atoms in a certain coherent superposition of the bottom states, not coupled to the excited state. Then, another independent coherent combination turns out to be empty and, thus, one may obtain inversion between the operating states with no total inversion in the transition. As a result, a resonant pulse propagating through the medium prepared in such a way will be amplified.

The main goal of this contribution is to extend the concept of AWI to the SR emission and to show that the *super-radiant emission without inversion* (SREWI) can also be observed when a low-frequency coherence is created in the system. The peculiarities of the SREWI are analyzed for a polyatomic system of three-level atoms (characterized by the Λ-scheme of operating transitions) (i) - placed into a high-Q cavity and (ii) - prepared in the form of a thin film of size less than the emission wavelength.

In case of the cavity SREWI, we discuss the effect of splitting of the lower atomic levels on the SREWI and show that the SREWI has a sufficient intensity at magnitudes of splitting, which even exceed the SREWI spectrum width. The reason for such behavior is an efficient exchange of coherence between the high- and low-frequency channels. The problem of creation of a low-frequency coherence necessary for the SREWI is analyzed in detail. Two schemes are suggested for doing that, first, applying a $\pi/2$-pulsed field and second, by means of a resonant low-frequency $\pi/2$-pulse, both of a duration T_P less than the SR emission delay time T_D. Normally, the latter is two orders of magnitude less than the duration of a single lobe of SR pulse. The SR emission in gases has sub-nanosecond time scale (see, for instance, [5]).

Then, to create a low-frequency coherence one should deal with a sub-microsecond low-frequency pulse. A preliminary study of the effects discussed was published in [6].

In case of the thin layer SREWI, the local-field effects are of great importance. The local field correction results in dependence of the resonance frequencies on the population difference between the operating levels, which in turn yields new features of the tree-level SR. We discuss in detail interplay between two possible channels of the SR emission versus their population difference relationship.

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Four-wave difference frequency mixing under the condition of coherent two-photon excitation

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In recent years, a considerable progress has been made in generating of tunable short-pulse VUV-radiation based on two-photon resonant difference-frequency mixing processes (FWDFM) in noble gases[1-2]. With pump pulses at frequency ω_p close to a two-photon transition frequency ω_{21} and injection pulses at tunable frequency ω_i short-pulse radiation at the difference-frequency $\omega_s = 2\omega_p - \omega_i$ has been produced with conversion efficiencies as high as several percents. If the pump pulse carrier frequency ω_p is tuned to resonance with the transition frequency and the pulse duration is short compared to the medium polarization relaxation time T_2' the effects of coherent radiation-matter interaction start to play an important role in the FWDM-process.

In this paper we demonstrate that the fs-pulse FWDM-technique, if proper modified, can be used for studying the temporal behavior of a two-photon transition driven by a strong pump laser field. Using time resolved FWDM scheme with femtosecond UV- and VUV-pulses and keeping the injected pulses (ω_i) significantly shorter than the pump pulses (ω_p) we were able to resolve two-photon Rabi oscillations and subsequent relaxation of the excitation at the probe difference- frequency (ω_s). The information is of prime importance for controlling and optimizing processes of two-photon resonant frequency conversion.

The pump and injected pulses were generated with 0.1 TW (8 mJ), 10Hz, 774nm Ti:sapphire "master laser". Forth harmonic generation in 3 BBO crystals to 193nm and subsequent amplification in an ArF amplifier module provides synchronized strong deep UV pump pulses and injection pulses at the 3rd harmonic (258nm) [2]. Pumping with strong 550fs, 193nm pulses and probing with the three times shorter injection pulses (ω_i) made it possible to resolve coherent dynamics of the excited transition. Using Ar and Kr as nonlinear media two qualitatively different pictures of the medium response behavior have been observed. In Ar where the frequency detuning from the two-photon resonance was large compared to the pump pulse spectral width (50cm^{-1}) a difference-frequency signal represented a shape directly related to that of the pump pulse intensity. In contrast, for two-photon resonant excitation of the $4p^6\ {}^1S_0 \rightarrow 6p[5/2]_2$ level in Kr the dependence of the signal on the delay time shows a slow decay and a signal could be detected for delays as long as 20-30 ps. We also observed an oscillating substructure in the region where the pump and the injected pulse had an substantial temporal overlap. The substructure appeared only at pump pulse energies exceeding a critical value of 0.35-0.4 J/cm^2. A theoretical analysis of the obtained data has shown that two-photon coherent Rabi oscillations in an intense resonant field were resolved.

On the base of numerical solution of the Maxwell-Bloch equation we predict the possibility of using two-photon coherent propagation effects for an additional pulse shortening [3]. The

nonlinear self-shortening occurs only in the regime where the injection pulse propagates with a well-defined temporal delay in respect to the pump pulse and interacts with the long-living coherent polarization created by the pump pulse. In this regime a nonstationary „two-color" pulse at the generated (ω_s) and the injection (ω_i) field frequency is formed whose duration gets shorter and intensity higher with the propagation distance. Our analysis shows that the self-compression mechanism can provide temporal shortening of the difference-frequency pulse up to factor 10 (in comparison to the input pulse duration) resulting in sub-100fs VUV pulse generation.

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Growth, Crystal-Chemical Structure and Site Spectroscopy of MF_2($M \equiv$ Ca,Sr,Ba) Crystals Doped with Rare-Earth Ions.

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It was determined earlier that rare earth ions (RE^{3+}) form in fluorite type crystals (CaF_2, SrF_2, BaF_2)several types of structuraly degenerated optical centers,marked as L,M,N,M', N',Y.

The concentrations and the behaviour of these centers under external conditions depend on the laws of chemical thermodynamics. The application of thermodynamics laws to the
eguilibrium of RE^{3+} optical centers in fluorites gives opportunity to
determine relative and absolute concentrations of different centers and to control these concentrations.

The unique feature of RE^{3+} doped fluorites is that the absorption and luminescence spectra occurs inhomogeneously splitted, the value of this splitting being as high as 100 cm^{-1}, that is much higher than in other fluoride or oxide crystals. The high value of nonuniform splitting and good spectral resolution for different centers make fluorite crystals, doped with RE^{3+} ions unique object for selective and time resolved site spectroscopy.

Using tunable lasers of different types with pulse duration less than 10 ns, $10^2 \div 10^4$ pps, as an excitation source, and nanosecond single photon counting correlated technique at the temperature range of 1,6-300 K, the absorption,excitation and luminescence spectra with the resolution of 0,1 A, the kinetics of luminescence, the electron phonon interaction, the radiationless ion-ion interactions with characteristic times lying in nanosecond range, have been investigated. Besides the investigation of excited state absorption in 1,3 μm spectral range in different Nd^{3+} centers in simple and mixed fluorites was also carried out.

In all cases the experimental results were compared with theoretical considerations.

Optical Generation of Propagation-Invariant Femtosecond-Domain Localized Wave Fields.

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During the last decade a number of spatially and temporally localized solutions to homogeneous wave equations have been found, whose particle–like amplitude distribution propagates without any spread in free space (focus wave modes, X waves, Bessel beams, Bessel-X pulses, electromagnetic directed-energy pulse trains, Bessel-Gauss pulses, etc., see, e.g. Refs. [1-10] and references therein). Recently the concept of localized waves was generalized to design femtosecond pulsed light fields in such a way that they would maintain their strong longitudinal and lateral localization in the course of propagation into a considerable depth in a given linear dispersive medium [8,9]. As spatially and (or) temporally localized transmission of light energy is of great importance for various applications (e.g., optical communication, monitoring, imaging and femtosecond spectroscopy), the experimental implementation of such wave fields is of practical significance.

The feasibility of optical X–pulses (Bessel–X pulses) was verified in Ref.[8]. In our recent paper [10] we reported the first experimental measurement of the whole three-dimensional distribution of the field of optical X waves in free space. So far the experimental results on focus wave modes and the other above–mentioned localized wave fields have been obtained only in radio-frequency domain and in acoustic.

In this paper we introduce an approach that can be used to design optical schemes for generation of various localized wave fields. As an example, we propose a well–realizable scheme for generation of optical focus wave modes.

We will give a physical insight into the concept of localized wave propagation phenomena by introducing an alternative interpretation of the angular spectrum

representation of scalar localized wave fields [11]. Specifically, it will be demonstrated that the peculiar propagation properties of the localized wave fields are determined by geometrical shape of their angular spectrum supports. The plane wave decomposition of wave fields, due to its transparent physical interpretation, is an appropriate choice in our problem.

The proposed design process relies on the methods of geometrical optics and consists of two steps: (i) conventional optical elements (axicons, diffraction gratings) are combined in such a way that the angular spectrum support of the resulting wave field approximates that of the optical focus wave mode; (ii) the phase distortions are compensated to yield a band–limited output pulse – the pulse compression is accomplished using recently developed techniques in the field of ultrashort optical pulse generation (see, e.g.[12]) Numerical simulations show, that sub-10 fs highly localized optical focus wave modes propagating up to 1m without remarkable spatial and temporal spread, can be generated by the optical scheme designed.

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Gamma-Ray Lasing - Proposals for Tomorrow Feasible Experiments

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The problem of gamma-ray lasing attracts attention of many explorers for almost four decades. The reason is that solving this problem will -

* extend the basic principle of induced boson emission, successfully applied in the optical-laser physics, to a new class of quantum oscillators, namely, nuclei,
* open up opportunities for using in modern science and technology a new energy range of coherent photons (keV and even MeV),
* introduce into practice a new type of nuclear reaction, namely, the chain reaction of induced radiative transitions.

Beginning with very first Russian and American proposals the main concepts of stimulation of gamma-ray emission were based on making use of Moessbauer transitions in nuclei embedded in a solid matrix. Unfortunately this approach must be paid by numerous well known complications inherent for the solid state which are not surmounted until today.

We present detailed quantitative description of an alternative basic concept of *Gamma-Ray Lasing* by populations of *free unbounded* metastable nuclei as a contrast to the solid-state approach. This concept leans upon following main statements.

* The nuclear recoil accompanying every hard-photon radiative event causes the splitting of emission and absorption isomer lines. This makes possible to obtain a spectrally local (or, so called, hidden) inversion over limited interval of entire spectral line without total excess of number of excited nuclei over that of unexcited ones. Deep hidden inversion of such a kind can be easily achieved when the temperature of isomer population is lower than 4 K.

* Much more deep cooling down to microkelvin range is necessary to maximize the gamma-flux gain through tending to unity the ratio of radiative linewidth to the entire unhomogeneous width. Such a cooling or, best to say, monokinetizing the populations of free atoms or ions comprising isomer nuclei can be performed by various modern methods using laser-light pressure or by known electrokinematic method simply coming to high-voltage acceleration of charged particles. As result this cooling draws the nuclear cross-section of induced gamma-emission to the maximum value approximately equal to the wavelength squared.

* Two types of emission processes simultaneously supply photons into laser modes: spontaneous emission and amplification of gamma-radiation already existing in the laser modes

and also starting from spontaneous emission events. Both photon fluxes originated by these two processes are co-existing, but the latter must exceed the former one, if we want reliably detect the nuclear lasing effect. This demands that the minimum number of excited nuclei stored in amplification channel exceeds the critical value which can be estimated by 10^{12}-10^{14}.

* Pumping by intense non-coherent X-ray flux based on so called "two-level", Stokes and anti-Stokes schemes seemingly is the most efficient process providing the critical number of excited nuclei. These schemes act just like standard three-level pumping mechanism of an ordinary optical laser, but make use of only one upper level split into two radiative lines due to recoil effect. Very important advantage of "two-level" pumping mechanism is the large freedom of maneuvers across the table of isotopes while choosing the candidate nuclei with a proper level structure.

To sum up we present first draft of the laboratory setup with selfconsistent constituents and narrow calculations of distinct experimental procedures leading to reliable observation and investigation of true amplification of gamma-ray flux by free excited nuclei or, in other words, the gamma-ray lasing. We believe this draft shall provide good opportunities for tomorrow fruitful experimental activity.

Superluminal localized waves and their relation to tachyons

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The so-called diffraction-free monochromatic Bessel beam [1] was over the past ten years the only representative of nonspreading linear waves realized in optics, where it has found a number of applications up to laser-driven acceleration of elementary particles (see, e.g. [2]). Recently discovered wide-band wave-packet-type limited diffraction solutions to the linear wave equations of mathematical physics ("focus wave modes", "Bessel-Gauss pulses", "directed energy pulse trains," "X waves," etc., see, e.g. [3,4] and references therein), which maintain their spatio-temporally localized shape in the course of propagation, are also of practical significance in optics. An optical version of the X wave, named the Bessel-X pulse, was treated theoretically and its propagation-invariant high localization (e.g. $\sim 10^{-3}$ mm, $\sim 10^{-15}$ sec) was shown by computer simulations [5]. Specially designed femtosecond-duration Bessel-X pulses not only maintain their lateral localization but also the longitudinal one in dispersive propagation media [6]. Such a possibility to suppress the temporal spread caused by the group velocity dispersion has been experimentally verified on subpicosecond laser pulses [7] by making use of a computer-generated holographic optical element designed for formation of the common Bessel beam. First recording of the whole three-dimensional distribution of the field of optical X waves in free space was accomplished in Ref.[8].

In this presentation we give an overview of very recent results in the study of Bessel-X pulses and other limited diffraction waves, particularly, we consider possibilities of optical launching of various localized waves, and discuss some general issues in connection with the superluminal motion of the Bessel-X pulse.

Naturally, the pulse is not at variance with the special theory of relativity despite it exhibits a higher-than-*c* group velocity and other startling peculiarities. The Bessel-X pulse is just one of the examples of "allowed" but nontrivial superluminal movements studied recently in different fields of physical optics and astrophysics (see an overview in [9]). An interesting observation that the X pulse field resembles "observable" shape of tachyons [10], can be developed into new interpretation of these hypothetical particles along with the X waves.

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POLARIZATION OF FREE ELECTROMAGNETIC FIELD AND ELECTROMAGNETIC RADIATION IN QUANTUM DOMAIN

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This talk reports some new results relating to the quantum properties of polarization of electromagnetic radiation. It builds upon our earlier investigations [1,2].

The polarization properties of a classical radiation are usually specified by the Stokes parameters determined for a transverse field [3]. The quantum counterpart is provided by the Stokes operators which can be obtained by standard quantization of the field amplitudes [4]. At the same time, within the quantum physics, describing the radiation as a beam of photons, the polarization should be determined as a given spin state of photons, forming the beam. Since the spin of photon is equal to 1, it has three projections $m = 0, \pm 1$. Therefore just three spin states and corresponding polarizations should be taken into consideration.

An example of some considerable interest is provided by a dipole radiation when, due to the selection rules, the photons with angular momentum (spin) 1 are emitted. It is well known that even in the classical picture, the dipole radiation always has a longitudinal (L) component (with $m = 0$) in addition to the transversal (T) components (with $m = \pm 1$) [5]. Since L component decays with the distance quite rapidly, it is neglected in the far zone where the standard Stokes parameters for a completely transverse field are determined. Thus, the conventional definition of the Stokes parameters for a completely transversal (free) field should be considered as an approximation valid, for the dipole radiation, in the far zone.

However, it is not a case in the quantum domain where one cannot neglect L component *a priori*. Actually, even in the far zone, where L component contains very few photons and could be approximated by the vacuum state, it may contribute into the quantum fluctuations of different physical parameters.

To estimate the contribution of L component with no resort to the transversal field, let us consider classical tensor of polarization with the components which are slowly varying bilinear forms with respect to the complex electric field amplitudes. To take into account the angular momentum of radiation one has to use the multipole expansion of the field [5] which yields, on allowing for the dipole radiation, the rank 3 Hermitian tensor with 5 independent components out of nine [2]. Thus, the polarization of dipole radiation is specified by five real parameters, forming the set of five generalized Stokes parameters (GSP). Let us stress the difference

with the conventional case of a purely transversal field when the rank 2 tensor of polarization has only three independent components and polarization is specified by three conventional Stokes parameters (CSP).

To establish contact with conventional results, we specify GSP as three different linear combinations of intensities and cosine and sine of the azimuthal phase of the angular momentum of radiation [1,2]. With the assumption that L component has zero intensity, the set of five GSP is reduced into three CSP determined in the circular polarization basis [3].

The generalizes Stokes operators (GSO) can be obtained from (GSP) by quantization in the representation of spherical photons [1,2]. Let us stress here that just the spherical photons determine the states with given angular momentum (spin) while the "plane" photons determine the states with given linear momentum. In view of quantum interpretation of polarization, the use of spherical photons seem to be quite natural.

let us compare the conventional Stokes operators (CSO) [4] and GSO. Although both sets consist of the Hermitian operators, they have different commutation relations, determining different possibilities of measurement. Precisely, the CSO, describing the cosine and sine of phase difference between the two circular components, cannot be measured simultaneously which seems to be a bit strange. At the same time, corresponding GSO are the commuting operators since they are functions of one and the same operator argument. They also commute with the total intensity. In the case of L mode in the vacuum state and two circularly polarized modes in some states with nonzero intensities (say, in the coherent states), both GSO and CSO give one and the same set of averages. At the same time, the difference in the algebraic properties leads to a qualitatively different pictures of quantum fluctuations. The quantum fluctuations of polarization can be measured with the use of the eight-port operational scheme [6].

Thus, the neglecting of L component of the dipole radiation is a quite risky approximation in the quantum domain. Our results are valid for both electric and magnetic dipole radiations. Let us stress that the adequate description of quantum properties of polarization of an electromagnetic radiation is very important for the atomic physics experiments with non-classical light and for new light emitting devices such as a single-atom maser and a multiple-quantum-well structure in a microcavity. Some concrete examples are discussed.

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Intracavity laser spectroscopy with diode lasers

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Possible application of diode lasers for intracavity laser spectroscopy (ICLS) is investigated. Earlier attempts to apply diode lasers with antireflection coating deposited on the crystal faces to the ICLS failed in eliminating the "parasitic" spectral selection caused by interference on the crystal faces.

A special diode laser has been constructed and manufactured with an external nonselective cavity on the basis of specially elaborated diode sample with the output faces inclined at Brewster angle. Spectral kinetics has been investigated in various cavities, namely, double-mirror cavity with two Brewster faces of diode and with micro-objectives, and the cavity with one Brewster face and the second face normal to the direction of laser emission, the latter operating as the output mirror. In addition, systems without any objectives in the cavity were investigated. In the latter case, astigmatism was compensated by using external spherical mirrors shifted slightly from the cavity axis. The best spectral kinetics and lowest interference effects in the output spectrum were observed with the trapezoidal shape of active medium whose one normal face served as the output mirror. In the case of two Brewster faces, noticeable interference effects are observed in the emission spectrum despite of the small diameter of active medium. The spectral kinetics was investigated as a function of puls duration and the excess of pumping power over the threshold value. In order to achieve maximum stability of spectral kinetics we suggested an original scheme for pumping a diode by two-step voltage pulse. The first-step pulse whose amplitude was below the threshold value heats the diode crystal to quasi-equilibrium temperature whereas the second-step pulse (exceeding the threshold value) makes diode to emit. With diode laser under consideration the first intracavity absorption spectra have been obtained. The corresponding sensitivity was 100 times greater than the sensitivity in the case of absorbing sample placed outside the cavity.

Collimation Mechanism for Atom Lasers

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Abstract

A mechanism is suggested for creating well–collimated beams of neutral spin–polarized particles by means of magnetic fields. This mechanism can be used in atom lasers for the formation of directed coherent beams of atoms. The directed motion of atoms is achieved only with the help of magnetic fields, no mechanical collimators being involved.

A device emitting a coherent atomic beam, similar to a laser radiating coherent photon rays, is called *atom laser*. Bose atoms can be prepared in a coherent state by cooling them in a trap below the temperature of Bose–Einstein condensation. To form an output coupler, one uses short radio–frequency pulses transferring atoms from trapped states to an untrapped state. However, when escaping from a trap, atom fly out in all directions. To force these escaping atoms to move in one preferable direction, one employs some mechanical blocking devices or additional laser beams.

In this report we suggest a new mechanism for creating well–collimated beams of neutral atoms. This mechanism does not require any mechanical blocking or additional laser operation. Collimation of an atomic beam is achieved only by means of magnetic fields of a trap. A particular configuration of a trap magnetic field, leading to a semiconfining regime of motion has been studied [1-3]. Here we generalize the consideration showing that there exists a large class of magnetic fields permitting one to create directed beams of atoms. This mechanism can be used for atom lasers.

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Use of a Wavelength Modulated Er^{3+} -Yb^{3+} Doped Fiber Laser for Sensitive Detection of Acetylene

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Abstract:

A wavelength modulated Er^{3+} -Yb^{3+} doped fiber laser has been developed and used in combination with a high sensitivity balanced ratiometric detection technique to detect trace amounts of acetylene and ammonia. Sensitivities in the ppmv-m range are predicted. The wavelength modulation technique is generally applicable to other fiber laser systems as well.

Paper Summary:

Highly sensitive field viable techniques for the measurement of gas concentrations have been a subject of interest for many years. Intracavity laser techniques were introduced early on, but it was found that the increase in sensitivity relative to traditional absorption spectroscopy was highly dependent on a complex experimental setup which was necessary to obtain quantitative results. This approach requires considerably more equipment than traditional absorption spectroscopy and due to the inherent instabilities associated with the intracavity techniques, and the lack of cheap components further out in the infrared, intracavity spectroscopy, although potentially very sensitive, has still not been demonstrated as a field viable technique. However, recently single longitudinal mode semiconductor diode lasers in combination with noise suppression techniques have allowed for highly sensitive field viable gas concentration sensors. Wavelength swept fiber lasers are also attractive because the broad wavelength range accessible to fiber lasers overlaps with the absorption spectra of various molecules. In this article, we discuss the unique combination of a wavelength swept fiber laser with a noise suppression technique to reach ppmv-m sensitivity of acetylene. The potential sensitivity here may be much higher as it is possible to combine this technique with a multipass configuration.

The combination rotational-vibrational band of acetylene in the 1.54 μm region has been noted by other investigators [1]. Here we describe a novel combination of a wavelength swept Er^{3+} -Yb^{3+} fiber laser light source with a sensitive noise cancellation circuit. This allows for sensitive detection of both acetylene and ammonia. The experimental setup is relatively simple and compact and this configuration has the potential to be used for other fiber laser wavelengths which coincide with stronger absorption lines in the near infrared. The Tm^{3+} fiber laser system which can be made to lase from 1.65 to 2.1 μm is a very good candidate and is currently being investigated.

The experimental setup used in this investigation can be described as follows: A 100 mW pigtailed diode pump source operating at 980 nm was fused onto a 3 dB coupler designed for 1550 nm. About 75% of the pump radiation coupled into the active arm while the remaining power was embedded in index matching gel. The fiber

laser cavity itself consisted of a fiber Bragg grating (FBG), a 20 cm piece of Er-Yb fiber and a 65 cm long gold tipped section of telecom fiber. There were large core to core mismatches between the fiber containing the Bragg grating and the active fiber so the threshold was relatively high. The grating itself was written with a 1.07 μm period phase mask which for the fiber implemented here (n_{core}=1.449 at 1550 nm) corresponds to a grating reflective wavelength of 1551 nm. In order to allow the laser wavelength to overlap with stronger acetylene lines, the fiber was strained during exposure to the UV radiation used to write the grating. In the final configuration, the grating had a peak reflectivity near 1548 nm. The output of the fiber laser was taken from the remaining port of the 2x2 coupler. It was passed through an isolator and collimated and finally split into a signal and reference beam which were detected by InGaAs photodiodes and fed to the noise cancellation circuit [2]. In this circuit, the photodiode currents are balanced electronically obviating the need for equal power levels in both signal and reference arms and allowing small absorbances to be detected. In order to sweep the laser wavelength across the absorption line shape, we relied on the fact that the FBG center wavelength is sensitive to strain. One end of the grating was immobilized in epoxy while the other end was attached to a PZT actuator with a total extension of 90 μm. This allowed the fiber laser to be tuned across approximately 3 nm. It was possible to dither the laser about a certain wavelength at a rate of several hundred Hz by applying a triangle wave to the PZT driver.

In our experiment, various gas concentrations were placed in a cell directly in the path of the signal light. The wavelength of the laser was modulated at 10 Hz and the log ratiometric balanced detector output showed a dip when the absorption line was scanned. The depth of this dip was proportional to the concentration of the species. The resolution of the spectra obtained depends on the linewidth of the fiber laser which was approximately 1 GHz for our system. Analyzing this information and accounting for the fact that the peak absorption of acetylene is at 1531 nm, one can predict that ppmv-m sensitivities will be achieved with this wavelength modulated fiber laser-balanced detector approach. Higher sensitivities may be possible for other species which absorb more strongly than acetylene. In conclusion, a simple, sensitive, compact sensor for acetylene has been demonstrated, and the general approach is applicable to the detection of other molecules which absorb under the tuning ranges of other rare earth doped fiber lasers.

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LASER SPECTROSCOPY

High-precision laser spectroscopy today and tomorrow.

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Methods of high resolution laser spectroscopy of helium

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The basic methods of high resolution laser spectroscopy for the 2^1S-2^3S transition of helium (saturated absorption, two-photon absorption and stimulated Raman scattering) have been analyzed.

Raman spectroscopy for water temperature sensing

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Abstract

We present an experimental study of the Raman spectrum of pure and sea water with respect to the temperature an to the salinity dependence, in both pulsed and cw experimental conditions. For both the cw and the pulsed measurementes discussion and analysis of the results are presented. The results obtained with cw and pulsed excitation shows that the variation with temperature and salinity of the spectrum can be summarised in an effective marker for the Raman spectrum.

The Raman spectrum of water in the $3000 \div 4000$ cm^{-1} region, due to symmetric and antisymmetric stretching vibrations, has been studied for basic research and application to remote temperature sensing. These vibrations are Raman active in the gas phase (C_{2v} symmetry, A_1 and B_1 components) and appear at a Raman shift of 3832 and 3942 cm^{-1} respectively.

In the first studies of Raman spectra of the liquid water it was already shown that the Raman spectrum in the stretching region changes with the

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temperature. This characteristic of water Raman spectrum was studied and applied in laboratory experiments, which proved the temperature dependence of the polarization components of Raman scattering. The first in field measurement dates back to 1977.

In spite of the fact that the method was first proposed in seventies, there are few experiments done in field where, due to environmental costraints, the measurements have to be performed with pulsed laser sources. Moreover the comparison of the laboratory cw results with the pulsed field measurements is not completely satisfactory. In this contribution we present an experimental study of the Raman spectrum of pure and sea water with respect to the temperature and salinity dependence in both pulsed and cw experimental conditions. We have also performed an experimental analysis of the presence of stimulated Raman scattering and its influence on the temperature dependence of the spectrum. For both the cw and the pulsed measurementes discussion and analysis of the results are presented. The results show that the variation with temperature and salinity of the spectrum can be summarised in an effective marker for the Raman spectrum; moreover, referring to the temperature dependence of the marker, the cw and pulsed results are consistent within the experimental errors.

Finally in the conclusion we outline the limits and the validity of this method to measure temperature and/or salinity of water.

Alignment and orientation in Doppler free spectroscopy of rubidium

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We report about an experimental investigation of alignment induced resonance in Doppler free spectrum of D_2 absorption line of ^{87}Rb. The resonance appeared as a peak of absorption instead the peak of transmission at the crossover resonance between $^5S_{1/2}(F=1)$ - $^5P_{3/2}(F=0)$ and the $^5S_{1/2}(F=1)$ - $^5P_{3/2}(F=1)$ transitions. Earlier the resonances of the same nature were observed in [1] for ^{85}Rb isotope. In our case the chosen transitions provide fastest alignment and maximal amplitude due to simplest magnetic structure.

The effect observed in conventional experimental scheme for saturated absorption with using external semiconductor diode laser at 780 nm. Strong and probe laser beams were linearly polarized and passed through the Rb cell in opposite directions. A power of strong field could reach several mW. Laser linewidth was less than 1 MHz and was much smaller the natural linewidth (6 MHz). Continuous tuning of the laser frequency was about 10 GHz without mode hopping. This range was enough to cover all of the D_2 doppler-free resonances splitted by hyperfine interaction. Laboratory magnetic field was controlled by Helmgoltz coils in all directions.

Maximal amplitude of observed resonance was achieved at weak magnetic field oriented along the polarization vector of laser beams. In this conditions the both transitions have full and fast alignment in the present of strong field. Measured probe absorption is a sum of signals corresponding to two groups of atoms moving in opposite directions. For one of them the strong beam is tuned to $^5S(F=1)$ - $^5P(F=0)$ resonance and the probe beam is tuned to the $^5S(F=1)$ - $^5P(F=1)$ resonance. At the same time for another group the inverse case is realized. At the crossover resonance then we have doubled growing of probe absorption.

The amplitude of the resonance could serve for control of alignment. It depends upon the relation between the alignment and Zeeman sublevels relaxation rates and may be calculated numerically. Such calculations were developed in [2] for D_2 line of ^{85}Rb isotope. Also one can see that width of the resonance is noticeable less compared with conventional doppler-free resonances. The reasons of this effect will be discussed. The role of collisions will be considered.

In report we shall discuss the results of probe field spectroscopy experiments of velocity selective optical pumping of rubidium at D_1 and D_2 lines by circular polarized laser radiation.

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Control of photoionization products by quantum interferences

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Abstract

Coherent control provides a quantum interference based method for controlling atomic and molecular dynamics. We report the experimental observations of different ways to achieve such a control in the atomic photoionization continuum.

During the past three decades the study of quantum-mechanical interference between transition amplitudes into the atomic ionization continuum has been a field of great interest. In particular the possibility of controlling bound-free transitions as been predicted theoretically and investigated experimentally in atomic and molecular gases, and in semiconductors. This control is possible when the two pathways lead directly to the same continuum state.

One way to achieve this condition is done by an excitation scheme inducing one- and three-photon ionization, modulating the ionization by changing the phase difference between the two fields. Inducing this interference process directly into the continuum minimizes restrictions on the required wavelength and puts in evidence a quantum interference effect where the continuum plays a crucial role. We present our experiment performed in a sodium beam. The sodium atoms, initially prepared in the $3P_{\frac{1}{2}}$ excited state, were photoionized by a non resonant three-photon interaction with 1064-nm laser light and by a

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one-photon interaction with the third-harmonic field, at 355 nm. Interference between the two transition paths allows the control of the total ionization rate by varying the relative phase of the laser fields.

A different way to get coherent control is to induce a resonance into the ionization continuum. It is now well established that the coupling of a discrete state of an atom to one of its continua by means of a coherent electromagnetic field induces a structure which may be probed through the absorption of a second laser field. The effect, established as laser induced continuum structure (LICS), has been in recent years demonstrated in different experiments utilizing a variety of coupling schemes including bound, as well as autoionizing states. An important feature of the phenomenon is that it is electromagnetically induced: the dressed continuum exhibits a structure controllable through the parameters of the coherent dressing field (wavelength, intensity, bandwidth). The existence of continuum structure and its characteristics are conventionally considered to be determined by the atomic parameters only. Hence the ability of LICS to provide control in position and shape of the induced or modified continuum structure is of particular interest. Here we report on our recent work on this effect.

Finally we report the observation of the modification through LICS of a quantity which is commonly meant to depend only on the atomic structure parameters: the branching ratio in the photoionization of xenon. In this experiment, the multiphoton radiative decay of the xenon ground state into the two electronic continua, that correspond to the two fine structure levels of the ground state of the xenon ion, is varied by electromagnetically embedding a bound state of the atom into the two continua.

All the measurements here presented are performed in atomic beam apparata, which use a time-of-flight spectrometer for energy analyzing the emitted photoelectrons. The schemes proposed are suitable also for ionization and dissociation into a molecular continuum.

Precise Femtosecond Spectroscopy of Raman atoms' transition

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If the spectral width of the pulse is sufficiently wide, the coherent interaction between pulse and multilevel medium becomes possible. For the multilevel configuration it was shown that the level population depends on the time between pulses as a superposition of harmonic oscillations with frequencies of fine (hyperfine) structures. This confirmation is illustrated by an example of five-level configuration of Rb. The first obtained experimental results on stabilization of the pulse repetition frequency showed that the stability of the repetition frequency of the femtosecond Ti: Al_2O_3 laser pulses was at least 2.10^{-12} in 10 s. We propose to use this phenomena for the high resolution spectroscopy and for the creation of new type of optical standard.

Spontaneous emission-induced coherent effects in absorption and dispersion of a V-type three level atom

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We study the effects of quantum interference from spontaneous emission in the creation of atomic coherence in a closed **V**-type system. We find that the absorption and dispersion properties of this atom can be significantly modified if this interference is optimized. Lasing without inversion, electromagnetically-induced transparency and enhancement of the index of refraction are all dependent on this interference.

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In this article, using a closed V-type atomic system which is excited by two different laser pulses (a strong drive field and a probe field), we investigate the effects of coherence created from spontaneous emission interference in the absorption and dispersion properties of this atom. Our atomic system is similar to that studied in reference [1]; however, the effects of quantum interference deriving from the spontaneous emission of the two closely spaced upper levels which are included in our model will substantially modify the behaviour of the system [2]. We study the system in two separate cases: with and without the presence of a pump mechanism. For our pump mechanism, we choose to study only the case of an incoherent pumping (broad-bandwidth field). Using a steady state density matrix analysis we show that, in the presence of an incoherent pumping field, a transparency of the medium to the probe field can be induced from coherence which originates fro om spontaneous emission interference. In addition, the gain for LWI and the enhancement of the index of refraction increase as this interference increases. In the absence of incoherent pumping, the effects of EIT, LWI and enhancement of the index of refraction co-exist at the same time and these phenomena can be controlled using the coherence induced from spontaneous emission interference.

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OPTICAL SUPERFLUORESCENCE TRANSIENTS

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ABSTRACT

Picosecond optical excitation pulses two-photon resonant with the 5S - 5D transition in Rubidium vapor give rise to both regular and yoked superfluorescence emissions. Regular superfluorescence occurs on the 5D - 6P transition, yoked superfluorescence on the 5D - 6P - 5S transition. In all cases the superfluorescence emissions are temporally separated (i.e. delayed) from the excitation pulse.

When the two-photon resonant excitation pulse is made up of two overlapping (both temporally and spatially) components directed along $\mathbf{k}_1$ and $\mathbf{k}_2$ we find that the yoked superfluorescence emission on the 6P - 5S transition appears on a cone. This is result of simple phase matching and demonstrates that the superfluorescence emission on the 5D - 6P transition to which it is yoked must also be directed along a conical surface. In fact, there is a degenerate case in which the yoked emissions are actually directed along opposite directions.

When a sequence of three, temporally separated, two-photon resonant excitation pulses are applied, a series of delayed emissions are observed on the 6P - 5S transition. Some of these emissions are photon echoes whose origin can be traced to the direct action of the yoked superfluorescence emissions acting themselves as excitation pulses while others can be traced to a kind of indirect second harmonic echo effect.

The result outlined above are discussed in detail as well as the experimental conditions under which they are obtained.

Quantum beats in molecules. Creation and manipulation of coherences.

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Quantum beat spectroscopy is an essentially Doppler-free technique with a resolution limited only by the lifetimes of the coherently excited states.[1] This powerful, time-domain spectroscopic method is particularly suitable for the investigation of the structure (eg nuclear hyperfine constants, electric dipole moments, Landé g-factors) and dynamics (intramolecular relaxation) of jet-cooled molecules, transient radicals and van der Waals complexes.[2] Using clean coherent laser excitation of molecular states with detection of the evolution of the coherences by emission or multiphoton ionization, we discuss quantum beat spectroscopy performed on a nano- and microsecond timescale with the benefit of a long observation time and in consequence with high frequency resolution.[1]

In the first part of the account we shall focus on double resonance experiments with quantum beat detection after UV-RF excitation[3] as well as with the IR-UV pump-probe technique. The second and main part will be concerned with the creation and manipulation of coherences in molecules by a switched magnetic field. These effects are demonstrated with Zeeman quantum beats in electronically excited states of the molecule CS_2.

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Intensity Resonances at the Fundamental Frequency of a Two-Frequency Nd^{3+}:YAG Laser with an Intracavity Nonlinear-Absorbing CO_2 Cell

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Abstract

The results of theoretical and experimental investigations of intensity resonances at the wavelength of λ=1.064 μm in a two-frequency diode-pumped Nd^{3+}:YAG laser with linear and mutually orthogonal-polarized modes and an intracavity nonlinear-absorbing CO_2 cell are presented. It has been derived differential equations to describe the interaction of oscillation modes in a two-frequency solid-state laser with a nonlinear-absorbing medium. Numerical computations were made to determine the contrast and the width of intensity resonances as functions of the pressure of CO_2 in the absorbing cell and the excess of the gain over losses. These dependencies were compared with the relevant experimental dependencies.

The development of the methods for the selection of narrow optical intensity resonances in radiation of lasers of different types is associated with the creation of optical frequency standards and their applications in high-resolution spectroscopy. It is well known that only a limited number of atomic and molecular transitions fall within the range of the fundamental frequency of a Nd^{3+}:YAG laser. Therefore, the problem of how to find suitable absorber in this laser remains urgent nowadays.

One of the rapidly growing directions of investigations near IR range frequency standard is currently related to the study of amplitude and frequency resonances in two-frequency lasers with linear and mutually orthogonal-polarized modes and an intracavity nonlinear-absorbing cell. Due to mode competition, the amplitude of intensity resonances in such lasers is considerably higher than that in single-frequency

lasers. Therefore, two-frequency lasers provide an opportunity to implement a highly sensitive method to obtain resonances of saturated dispersion [1].

This paper presents the results of theoretical and experimental investigations of intensity resonances at the wavelength of λ=1.064 µm in a two-frequency diode-pumped Nd^{3+}:YAG laser with linear and mutually orthogonal-polarized modes [2] and an intracavity nonlinear-absorbing CO_2 cell.

The choice of CO_2 as an absorbing gas is associated with the possibility to employ this molecule as a high-Q frequency reference object in designing an optical frequency standard based on a Nd^{3+}:YAG laser [3]. The transition of a CO_2 molecule employed in this study is characterized by a moderate radiative width (about 170 Hz) and small collisional broadening (about 9.3 kHz/mTorr). Yet another advantage of a CO_2 molecule is the absence of Stark and Zeeman effects in the dipole approximation, which implies the stability of the resonance with respect to variations of external electric and magnetic fields.

The possibility to obtain an intensity resonance was analyzed with the use of a two-frequency diode-pumped Nd^{3+}:YAG laser, which was developed recently by our scientific group. Experimental studies were performed with a setup based on a recently designed two-frequency Nd^{3+}:YAG laser with a nonlinear-absorbing CO_2 cell, where the pressure of absorbing gas can be varied within a broad range (from several millitorrs up to the atmospheric pressure). The detection system allowed us to register amplitude and frequency resonances and to investigate their characteristics.

Differential equations have been derived to describe the interaction of oscillation modes in a two-frequency solid-state laser with a nonlinear-absorbing medium. These equations also describe the interaction of orthogonal-polarized modes with each other both in spatial inversion hole burning and in variation of the longitudinal spatial shift between the nodes (and antinodes) of standing electromagnetic waves introduced by an intracavity phase-anisotropic element (see [2]).

Numerical computations enabled us to determine the contrast and the width of intensity resonances as functions of the pressure of CO_2 in the absorbing cell and the excess of the gain over losses. These dependencies were compared with the relevant experimental dependencies. We have determined the optimal parameters of the active and absorbing media and the cavity that ensure the minimum width and the highest contrast of the resonance.

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Collisional Relaxation of Excited Levels of B State in I_2 and A^2B_1 State in NO_2 and Laser Complex for Monitoring of Molecular Iodine Isotopes ($^{127}I_2$ and $^{129}I_2$) and NO_2 in Atmospheric Air

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Abstract – The processes of collisional relaxations of vibrational levels of the B state in I_2 and A^2B_1 state in NO_2 – collisional predissociation, vibrational relaxations and collisional broadening of resonance absorption lines - for buffer gases with different physical and chemical properties, including He, Ne, Ar, Xe, H_2O, O_2, N_2, NO, NO_2, CO_2 and HNO_3 are investigated. A laser complex for continious real-time detection of iodine-127, iodine-129 and NO_2 in the atmospheric air is developed. The complex can be used for the ecological monitoring of the iodine isotopes and NO_2 concentrations in atmospheric air down to the level of maximum permissible concentration.

The task of constructing highly sensitive detectors for continious monitoring of the molecular iodine isotopes ($^{129}I_2$, $^{127}I_2$) and NO_2 is highly topical because of a number of scientific and practical, including ecological, applications.

One of the most promising methods of the detection these substances is the laser-induced fluorescence method [1-4]. In paper [2] were made an investigations of the influence of temperature and of the frequency of the exciting radiation on the fluorescence of I_2 vapor excited by 633 nm He-Ne laser radiation. In [3] it was shown that a 633-nm He-Ne and 442 nm He-Cd lasers can be successfully used for detecting impurities iodine isotopes and NO_2 in gases, in particular, in the working medium in reprocessing waste nuclear fuel on radiochemical plants to improve its ecological safety.

This paper is devoted to a study of the fluorescence of $^{129}I_2$, $^{127}I_2$ and NO_2 with the aim to increase the sensitivity of detection of these substances for ecological monitoring of the atmospheric air.

We proposed to investigate the processes of collisional relaxations of vibrational levels of the B state in I_2 and A^2B_1 state in NO_2 – collisional predissociation and vibrational relaxations – and collisional broadening of resonance absorption lines for buffer gases with different physical and chemical properties, including He, Ne, Ar, Xe, H_2O, O_2, N_2, NO, NO_2, CO_2 and HNO_3. The radiation sources have been a He-Ne laser in the case of I_2 and a He-Cd laser in the case of NO_2.

We determined the rate constants of collisional predissociation K_p, vibrational relaxation K_v B state of molecular iodine (v'=6, 11 $^{127}I_2$ and v'=6, 8, 12 for $^{129}I_2$), A^2B_1 state of NO_2 and coefficietns of collisional broadening K_{br} of resonance absorption lines.

Based on results of our investigations we proposed a laser complex for continious real-time detection of iodine-127, iodine-129 and NO_2 in the atmospheric air with the sensitivity up to 10^8 mol/cm^3 for I_2 and up to 10^{11} mol/cm^3 for NO_2. The demonstrated sensitivity proves that the elaborated laser complex can be used for the ecological monitoring of the iodine isotopes and NO_2 concentrations in atmospheric air down to the level of maximum permissible concentration.

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Photoelectric registration of multiphoton absorption spectra in wide-band gap crystals

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Fast registration technique of transient photoconductivity and tuneable optical parametric oscillator-amplifier were applied to multiphoton spectroscopy in alkali halide crystals. Degenerate and non-degenerate modifications of two-quanta excitation experiment were realised demonstrating efficient free electron generation not only for band-to-band optical transitions but also for exciton absorption. The last was attributed to thermal ionisation of exciton states at room and higher temperature. The photoconductivity spectra obtained allowed calibration by two-photon absorption directly measured at the fixed wavelengths.

Optical components of solid state laser system, operating at a high intensity level of pulsed radiation, are able to change their characteristics due to variety of non-linear effects following light-matter interaction. Compared to the others, multiphoton absorption in the initially transparent material not only induces transient modification of optical density, free electrons and exciton states it creates are able to launch processes of radiation defect formation or stimulate an avalanche ionisation leading to optical breakdown. So the experimental investigation of multiphoton absorption and following physical phenomena seems to be vital for elucidation of fundamental mechanisms of laser damage.

Generation of non-equilibrium carriers in the conduction band of wide-band gap crystals resulted from multiphoton transitions can be detected by transient photoconductivity technique (TPC) [1], applied in the present work to investigate two-photon excitation spectra in the alkali halide undoped crystals. The method imply registration of a short pulse of transient current through the bulk of the sample positioned in a photoconductive cell partially illuminated by intense laser radiation. The photoconductivity signal measured origins from short distance drift of free carriers which do not typically reach the sample boundary. TPC method shows high

sensitivity comparable to luminescence registration technique [2] and enables investigation of dynamics of the excited state in subnanosecond time scale. As a source of short (~1 ns) intense laser pulses we used specially developed optical parametric oscillator-amplifier (OPO) tuneable through the visible range of spectrum (440÷680 nm). Two variations of the experiment included optical excitation of the materials by two quanta of OPO signal wave output and by combination of OPO radiation with a UV laser source operating at a fixed wavelength of 266 nm. In the available tuning range we investigated spectral, temperature and polarisation dependences of free carrier excitation and spectral dependence for the linear recombination time, demonstrated calibration of the obtained spectra by non-linear absorption coefficient directly measured for combination of fixed wavelengths of laser radiation (532 nm and 266 nm).

In course of experiments an efficient free electron generation was demonstrated not only for two-quanta transitions into conduction band, but also for two-photon exciton absorption. An analysis of the obtained spectral and polarisation dependences and comparison to conventional photoconductivity spectra [3] indicated thermal ionisation from the exciton energy levels in the temperature range above 300 K. Activation energy in KI was measured and found to coincide with the location of energy levels, allowed for two-photon exciton transitions.

The results obtained qualify transient photoconductivity as an effective tool for investigation of multiphoton absorption and dynamics of free electrons in wide-band gap crystals. Versatility of the approach developed was also demonstrated for spectroscopy of impurity levels and single photon interband transitions in wide-band gap dielectrics and semiconductors.

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Generation of sub-ps IR-pulses via parametric processes and application to transient spectroscopy of molecules

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Abstract

Intense pulses for 2-color pump-probe spectroscopy in the mid-infrared are generated by parametric stages. Frequency down conversion yields pulses from 2.6 to 7 μm with a minimum duration of 0.5 ps while independent adjustment of the pulse duration is achieved from 0.5 to 2.6 ps. First application to time-resolved spetroscopy is demonstrated.

Transient spectroscopy in the infrared spectral region with ultrashort light pulses was demonstrated to be a versatile tool for the investigation of fundamental interactions in liquids and semiconductors.[1] Independently tunable pump and probing pulses are highly desirable in these studies in order to provide full information on the different dynamical processes. Unfortunately existing laser systems suffer from some shortcomings as long pulse durations, one color operation, restricted tunability and/or energy and further more. Here we want to present an approach enabling independently tunable, intense pulses in extended tuning ranges with adjustable pulse duration. We start with a pulsed, flashlamp-pumped Nd:YLF laser utilizing Kerr-lens mode-locking and electronic feedback-control. The laser emits $\approx$ 550 pulses with 2.7 ps duration and 1.2 μJ energy at a repetition rate of 50 Hz. The frequency-doubled laser radiation is well suited for the synchronous pumping of two singly resonant optical parametric oscillators in parallel. An advantage of deriving tunability from OPO's and not from seeded OPAs is the possibility to adjust the pulse duration by the operation conditions of the OPO: With the pump intensity a factor of about 1.5 above threshold we obtain stable operation of the OPO with a pulse duration of $\simeq$ 3 ps. Increasing the pump intensity further and adjusting the length of the OPO appropriate yields shorter pulses in the range 0.3 - 3 ps. To this end, the energy of the second-harmonic pulse train is adjusted by a half-wave plate with step motor drive and a subsequent polarizer. The synchronization between the two pulsed OPO's was investigated from cross correlation data yielding

a time jitter of 50 fs. Subsequent down conversion between a selected and amplified laser pulse at the fundamental and one pulse out of the OPO-pulse train results in the desired mid-infrared radiation. A common two crystal setup is used in the probe branch as parametric amplifier yielding pulses in the range of 1550 cm^{-1} up to 3800 cm^{-1} by adjusting the OPO frequency and angle tuning of the two $AgGaS_2$ crystals ($E \approx 10$ nJ). In the pump branch we apply a novel configuration to reduce the well-known dispersion-governed pulse lengthening in long amplifier crystals. In previous investigations of a two-stage OPA equipped with two 7 mm $AgGaS_2$ crystals pulses of 1.5 ps were obtained at an energy level of 10 μJ.[2] In order to circumvent dispersive pulse lengthening in the amplifier we replace each of the two long crystals by a stack of two $AgGaS_2$ specimens with 3 mm of length, separated by a suitable filter glass absorbing the idler component exhibiting the highest group-velocity. We succeed in the generation of pulses in the same wavelength range as stated for the probe with energies of up to 2 μJ, however. The duration of the mid-IR pulses is determined by two-photon absorption in a suitable semiconductor and we measure for the pump as well as for the probe component a minimum of 0.5 ps. Changing the operation conditions of the OPO's for the first time independent, continuous tuning of the infrared pulse duration is possible between 0.5 ps and 2.6 ps [3] making this laser system well-suited for time-resolved spectroscopy in the mid-infrared.
We will demonstrate first applications of this laser system to two color time-resolved IR-spectroscopy of molecules in the liquid phase.

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A Double-Mode He-Ne and He-Ne/CH_4 Lasers with Synchronized Modes.

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Abstract

Frequency modulation (FM) of a double-mode He-Ne laser and He-Ne/CH_4 laser with an intracavity absorbing cell is studied experimentally and theoretically at a modulation frequency approximately equal to the intermode beat frequency.

The results of studing amplitude and frequency characteristics, spectra of fluctuations of intensity and intermode beat frequency are reported. It is shown that a substantial decrease in the spectral density of the intermode beat frequency fluctuations in the frequency range which is close to the range of detunings of modulation frequency from intermode beat frequency where the regime of mode locking can be implement.

It is revealed that in the vicinity of the absorption line centre the intensity of every mode for certain system parameters displays resonance structures narrower than the homogeneous line width of the absorption line.

This occurs when the range of mode synchronization is near the absorption line centre and its size is less than the homogeneous width of the absorption line.

Various methods of selecting narrow resonances in gas lasers radiation are widely used in the design of optical frequency standards and in superhigh resolution spectroscopy.

One of the direction of the investigations is the study of a double-mode gas lasers with an intracavity absorption cell operating in a regime with two linearly and orthogonally polarized modes. These lasers are at present used successfully in laser spectroscopy and laser frequency stabilization [1]. Precision characteristics of such systems are determined by the level of fluctuations of intensity and the intermode beat frequency.

We performed experimental and theoretical investigations for He-Ne and He-Ne/CH_4 lasers which produced two linearly and orthogonally polarized modes with the possibility of varying the intermode interval $\omega_{12} = \omega_1 - \omega_2$ (ω_1, ω_2 are the frequencies of each lasing modes) in the range 3÷20 MHz. A well-known phase-anizotropic resonator was used for obtaining this oscillation regime. We placed a laser-active medium between phase-anizotropic wedges made of crystalline quartz, oriented so that their wedge-like sides were faced each other. The frequency interval between these modes was varied by shifting one of the wedges perpendicular to the cavity axis [2]. The cacity included a 40-cm tube filled with an active medium at a pressure of 2 Torr and a 75-cm absorbing cell. The laser cavity was about 1.5 m in length and was formed by a plane mirror and a mirror with a curvature radius of 2 m. The power transmission coefficients of the mirrors were 2 and 6% respectively.

The frequencies of each of the lasing modes were simultaneously changed in two ways. A fast frequency modulation (at $\Omega = 3 \div 20$ MHz) was superimposed on a slow scanning (at 5÷50 Hz) across the gain profile. For the slow scan we glued one of the cavity mirrors to a piezoelement. The fast frequency modulation was effected with a lithium niobate electro-optic modulator placed near one of the cavity mirrors. The

amplitude $\Delta\omega$ (deviation) of this modulation corresponded to a modulation index $\Delta\omega / \Omega \approx 0.02$.

We investigated the intensity and frequency characteristics of the double-mode He-Ne and He-Ne/CH_4 lasers and also the dependences of the level of spectral dencity of intensity and intermode beating frequency fluctuations at various fixed frequencies ω on modulation frequency Ω close to the intermode interval.

The investigations showed that synchronization strongly influences at the level of the frequency fluctuations at the fixed observation frequencies up to the frequency $\omega = \delta\omega_{12}^{*}$, there $\delta\omega_{12}^{*}$ determines tuning range of the modulation frequency from intermode beating frequency inside which the regime of modes synchronization takes place.

The investigations of the influence of the mode synchronization at the level of natural intensity fluctuations showed that in this case mode synchronization practically does not influence at its level.

Our experimental and theoretical investigations demonstrated that when the modulation frequency is approximately equal to intermode beat frequency in the vicinity of the absorption line center the intensity of every mode displays resonance structures narrower than the homogeneous line width of the absorption line and determined by the value of synchronization range.

Calculations were carried out in limits of Lamb theory developed for synchronization regime in double-mode laser with orthogonally polarized modes [3]. The calculated dependences confirmed the experimental results. The results obtained may be used for other lasers, for example, CO_2 lasers and solid-state lasers.

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Spectroscopic and laser properties $BeLaAl_{11}O_{19}$ single crystals doped with Cr^{3+}, Ti^{3+} and Nd^{3+} ions

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The new promising laser crystal $BeLaAl_{11}O_{19}$ (HALB) doped with Cr^{3+}, Ti^{3+} and Nd^{3+} ions were grown by the Czochralski technique. The spectroscopic and laser properties of impurity ions in this crystal were investigated.

MANIFESTATION OF ULTRATHIN Ni FILMS' FERROMAGNETISM REVEALED BY FOUR-PHOTON PICOSECOND SPECTROSCOPY

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The biharmonic pumping technique (BP, two tunable dye lasers with the pulse duration about 20 ps) was used in experimental investigation of four-photon nonlinear response (we measured the self-diffraction efficiency η versus frequency detuning Δ of the BP components) of ultrathin ferromagnetic films (Ni, the film thickness was L = 17-150 nm) and a number of quite different reference metal samples (ultrathin Bi and Au films with the same thickness) on thin ZrO_2 substrates. The main parameters of all the investigated samples were thoroughly controlled by the spontaneous Raman scattering and X-rays reflectometry techniques. We revealed existence of a specific wide two-photon resonant transition (at the room temperature, the resonant frequency was about 150 cm^{-1}, see Fig.1 below) on a side wing of the experimental dispersion curves for all the investigated Ni samples. With increase (or decrease) of the sample temperature (we changed the sample temperature T in the range from 100 to 400 K), this two-photon resonant transition frequency slowly decreased (or increased, correspondingly). To explain this experimental result, we developed a theoretical model, which took into account possible quantum-size renormalization of the sample energy spectrum, as well as, intraband and interband relaxation processes, selection rules for different electronic

transitions between different magnetic subbands, splitted due to the ferromagnetism of Ni films, heating of the sample electron subsystem due to absorption of energy of picosecond laser pulses (BP components), etc. An error of the used interpolation of electronic energy spectrum of bulk Ni samples into a full Brilluen zone was not more than 0.04 eV. In the course of our further computer simulation, we calculated a number of dispersion curves for a wide range of changing fitting parameters of the model. So, specific two-photon resonant transition, which was experimentally found for Ni films, was interpreted as a principally new direct manifestation of ferromagnetic properties of the investigated samples (existence of the energy gap which forms between the tops of $3d_{+1/2}$ and $3d_{-1/2}$ Ni subbands due to their ferromagnetic splitting).

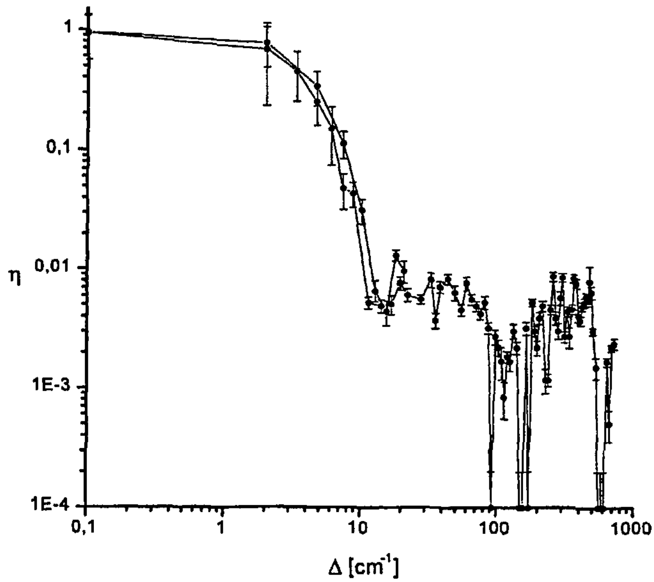

Fig.1. The self-diffraction efficiency η versus the frequency detuning Δ of the BP components: the film thickness L = 17 nm, the sample temperature T = 293 K.

INVESTIGATION OF LONG-LIVED STATES IN GASES BY USING COHERENT TRANSIENT TECHNIQUE

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Several examples of longlived states in atomic and molecular gases are considered. Their formation under laser radiation, mechanisms of decay due to interactions between particles, and applications in fundamental metrology and in optical informatics are analysed, and some aspects of applications are verified experimentally.

The lifetimes of quantum states are determined either by particles interactions (say, collisions in a gas) or by interactions with external fields or zero oscillations of electromagnetic field (radiative decay). Long-lived quantum states are of great interest for theory and practice of high resolution spectroscopy and for its numerous applications, like frequency standards design and optical data storage and processing.

Vibrational-rotational ground electronic levels of rarefied gases reveal characteristics of long-lived states due to low probabilities of radiation decay. However, Doppler broadening hides the fine and superfine structure in gases and hinders observation of long-lived states. Therefore various Doppler free techniques should be applied in the search for long-lived quantum states in gases.

Experimental registration of slow particles by using Doppler-free coherent transient spectroscopy was performed in molecular gas SF_6 [1]. This result has demonstrated the possibility to detect the duration of life more than 50 mcs; in the case of optimal photon echo signals formation, this duration may be increased till radiative lifetime.

Another kind of long-lived states arises under the action of coherent radiation, which results in creation of the polarization moments of levels in the rarefied gas. From the macroscopic viewpoint, this is

equivalent to induction of either macroscopic magneticity of gaseous sample (orientation), or quadrupole electric moment (alignment) or some higher moments. Specific external conditions are necessary to destroy these polarization moments, which, in its turn, explains their long life. Investigation of decay dynamics of such states provides important data on the matter. Such investigation is especially interesting in a gas media, which admits the variation of type and strengths of interaction between particles in a wide range. Besides, just in a gas the very effective technique, based on coherent transients, is applicable for investigation of polarization moments decay [2].

By using method of stimulated photon echo of specially chosen polarizations of exciting pulses, the generation and collisional decay of lower polarization moments (population, orientation and alignment) were investigated in molecular gas SF_6 and its mixtures with buffers Xe and He under excitation of CW frequency tunable CO_2 laser [3]. As a result of comparison of decay rates of polarization moments at different rotational-vibrational transitions od SF_6, the conclusion is made about possible J-dependence of these rates. On the base of comparison of population and higher polarization moments decay rates, the prevailed contribution of non-elastic collisions is revealed. Elastic part of decay rate, representing just depolarizing collisions, is characterized by small cross section (significantly lower than the gas kinetic one), is controlled by gas pressure.

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CW Laser Induced Fluorescent Spectroscopy of Highly Magnetised Collisionless Plasma

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The properties of resonant interaction of a cw monochromatic laser beam with ions of a collisionless plasma in high magnetic field (the order of Tesla) and laser induced fluorescence (LIF) were investigated both theoretically and experimentally. The ion rotational movement and the Zeeman splitting of energetic levels in strong magnetic field are crucial for resonant interaction.

The ion rotational movement results in change of plasma ion resonant frequencies as $\nu_x(t) = \nu_0 + \Delta\nu_D \cdot \sin(\omega_{ci} \cdot t)$ in the direction perpendicular to the magnetic field, where ν_0 is the central frequency of resonant transitions, $\Delta\nu_D = \nu_0\, v_\perp / c$ - maximal Doppler shift, $v_\perp = \sqrt{v_x^2 + v_y^2}$ - transverse velocity of the ion, $\omega_{ci} = eB / m_i$ - ion cyclotron frequency. The probability of resonant excitation by the laser beam perpendicular to magnetic field can be found by the Landau-Zener formula [1]:

$$W(1 \to 2) = 1 - \exp\left[-0.5\pi(\Omega_R / \eta)^2\right]$$

where $\Omega_R = \mu E_0 / h$ is the Rabi frequency and $\eta^2 = 2kV_\perp\omega_{ci}$. The effective time of the resonant interaction (T) of the laser beam of diameter d with the ions of velocity v is determined either by the time of flight $t_f \cong d/v$ or by the time of resonant interaction $\Delta\tau_{ci} \approx \gamma \cdot \omega_{ci}^{-1} \cdot \Delta\nu_D^{-1}$, where γ is the radiative transition width ($\gamma = \Sigma\gamma_i$). In the magnetic field of some Tesla, for ions with energy of the order of 1 eV and laser beam diameter of some mm, the Δt_{ci} is much lower than the t_f and is comparable to radiative lifetime $\tau = (2\pi\gamma)^{-1}$ of excited level.

The Zeeman splitting of transitions (the order of Doppler width) makes the optical pumping effect pronounced. Laser saturation intensity for interaction with optical pumping is determined by the expression [2] : $I_s' = 2I_s \cdot (1 + \tau / T) / (2 + \gamma_p T)$, where $I_s = h\nu_0 / 2\sigma_0\tau$, σ_0 is the peak value of the absorption cross-section of the resonant transition, γ_p is the rate of spontaneous emission to optical pumping levels. For $T \gg \tau$ (the usual case of atomic beam experiments) $I_s' = 2I_s \cdot (\tau / T) \ll I_s$. In our case when $T \cong \Delta t_{ci} \sim \tau$, the saturation intensity $I_s' \sim I_s$. It results from formal replacing T by Δt_{ci} .

The properties of LIF-signal are determined by the relations between η^2 (the rate of resonant frequency modulation), the Rabi frequency Ω_R , transition spectral width γ and

laser frequency detuning $\Delta=\nu_0-\nu_L$. They also depend on the relative values of the Larmor diameter of rotation d_H, the longitudinal period of helical trajectory of ions L_Z, the laser beam diameter d and the distribution function of ion velocities $n(v_x,v_y,v_z)$.

LIF-signal of highly magnetised ions with the Maxwellian distribution function $n(v_x,v_y,v_z) \propto \exp[-m(v_x^2+v_y^2)/2kT_\perp] \exp[-m(v_{oz}-v_z)^2 / 2kT_z]$ has the properties substantially different from the ones of neutral particles or ions in a weak magnetic field, when a one-dimensional model [3] for plasma particles motion along the magnetic field can be applied.

For $L_Z \le d/2$ and $d_H \ll d$, all the ions crossing the laser beam participate in the resonant interaction. As a result, the maximal fluorescence signal is proportional to the total particle flux through the interaction zone without the $\gamma / \Delta\nu_D$ factor.

An important change in the spectral distribution of the fluorescence signal can be observed in case of laser saturation intensity. For a fixed laser frequency ν_L and for the Maxwellian velocity distribution, the fluorescence spectral distribution is :

$$\rho(\nu_f,\nu_l) \propto (\nu_f-\nu_o)\cdot\left\{\pi + arctg\left[(\nu_l-\nu_o)/(\nu_f-\nu_o)\right]\right\} \times \exp\left\{-\left[(\nu_f-\nu_o)/\Delta\nu_D\right]^2\right\}$$

The total LIF-signal is $I(\nu_l)=\int\rho(\nu_f,\nu_l)d\nu_f \propto \exp\left[-(\nu_l-\nu_o)^2/\Delta\nu_D^2\right]$

The spatial distribution of LIF-signal is homogeneous in case of $L_H \ge d/2$. The optical pumping of metastable levels has no effect on the spatial z-distribution of LIF-signal. This is due to a transversal flux of the ions that have not yet participated in the resonant interaction.

Experimental investigations of the LIF were carried out on BaII magnetised plasma with B=(1- 3)Tesla. Continuous wave dye laser CR-699-21 (spectral width ≤1 MHz) with R6G was used for excitation of 614 nm and 583 nm BaII resonant transitions. LIF-signals were detected on 455 nm, 614 nm and 583 nm transitions. Spectral distribution of the fluorescence signal for laser saturation intensity, spatial distribution of LIF-signal and LIF-signal dependence from the laser intensity were investigated. The LIF-signal spectra of plasma heated by radio frequency with $\omega \cong \omega_{ci}$ were obtained. These spectra were used to obtain the distribution function of ion transverse velocities and transverse ion temperature $T_\perp$ with the spatial resolution less than $1\times1\times1$ cm^3.
The experimental results were in good agreement with the theoretical estimations.

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Coherent propagation in a two–photon absorber

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The propagation of an optical wave through a resonant two–photon absorbing medium is described by the two–photon Maxwell–Bloch equations. We will discuss various methods for obtaining analytical solutions and will give explicit solutions for some restricted problems.
i) For an incident purely *amplitude–modulated* wave and an arbitrary initial state of the medium, the problem is reduced to that of solving an ordinary differential equation [1]. (This generalizes an old result by Poluektov et al.[2])
ii) Hierarchies of solutions can be generated by means of *Bäcklund transformations.* In particular, a class of periodic solutions describing an intermediate pulse steepening has been established [3].
iii) More general *one–phase periodic waves* can be found, and their modulation has been studied by *Witham's method* [4].
iv) When restricted to low excitation of the medium, the equations of motion become mathematically equivalent to those describing second harmonic generation. Then the *inverse scattering method* will be shown to yield a successive approximation scheme. In the case of an incident square pulse, detuned with respect to the two–photon transition, the procedure becomes purely algebraic.
v) For the general Maxwell–Bloch equations of degenerate two–photon propagation (in one space dimension and without inhomogenous broadening) the applicationof the inverse scattering method is possible " in principle", even with arbitrary phase variations. Future work will determine its utility.

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Femtosecond Dynamics of A^2B^6 -Metal Microcavity Polaritons

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Abstract

Dynamics of semiconductor microcavity modes in A^2B^6-Metal structures were investigated by femtosecond pump-supercontinuum probe spectroscopy in wide spectral region 1.6 - 3.2 eV. The change of reflectivity of thin semiconductor (ZnS, ZnSe) films on thick metal (Ni, Cr, Cu) film on quartz substrate was monitored. Three different pumping photon energies $\hbar\omega_{pu1} = 2.34$ eV, $\hbar\omega_{pu2} = 2.75$ eV and $\hbar\omega_{pu3} = 5.5$ eV were used for the microcavity excitation and produced different photoresponse spectra. For the pumping energy below the energy gap of semiconductor the laser pulse excites mainly electrons of metal (i.e. boundary of the microcavity) and of semiconductor layer (by two-photon absorption). Nonequilibrium carriers of metal penetrate through Schottky electron barrier into the semiconductor. For the pumping energy above the energy gap of semiconductor the laser pulse is practically totally absorbed in thin surface layer of semiconductor and creates nonhomogeneous hot carriers distribution in semiconductor. The differences in the processes of carrier excitation are responsible for the differences in the changes of dielectric functions of semiconductor and metal and for the differences in the dynamics of cavity modes.

SPECTROSCOPY of SINGLE TRAPPED IONS and APPLICATIONS to FREQUENCY STANDARDS and CAVITY QUANTUM ELECTRODYNAMICS

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Summary

Single ion trapped and laser cooled provide ideal objects for high resolution spectroscopy and frequency standards. For the latter purpose we are investigating the $5s^2\ {}^1S_0$ - $5s5p\ {}^3P_0$ transition of In^+. With a natural linewidth of only 1.1 Hz this resonance offers very high resolution and is highly immune to frequency shifts due to external electromagnetic fields, because it connects two levels with vanishing electronic magnetic momenta. The wave-length of this clock transition is 236.5 nm and is technically very convenient, since it coincides with the fourth harmonic of the 946 nm Nd:YAG laser line. So this intrinsically frequency stable solid-state laser can be used to excite the transition. For laser cooling and fluorescence detection of the indium ion the $5s^2\ {}^1S_0$ - $5s5p\ {}^3P_1$ transition at 230.6 nm can be employed. The use of the relatively narrow intercombination line for laser cooling allows us to study optical sideband cooling in the strong binding regime, where the oscillation frequencies of the ion in the trap (around 1 MHz) are large than the optical linewidth of 360 kHz. In this parameter range laser cooling is possible to the quantum ground state of the vibrational motion in the trap corresponding to a temperature of roughly 100 mK. The same low temperature was obtained with sideband cooling of a small Coulomb crystal consisting of two ions, creating an interesting new quantum few-particle system.

It has been shown recently that it is also possible to use a single trapped ion as medium for a laser. Such a device is suitable to demonstrate typical quantum phenomena not present in a normal laser system. Furthermore, this laser allows to study phenomena resulting from the overlap of light and particle waves.

Multi-atmospheric e-beam sustained Ar-Xe laser

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Abstract
High density Ar-Xe gas mixtures are very attractive for laser systems because of attainable power density and efficiency. The most productive system is based on a pulsed e-beam sustained discharge. Efficiencies up to 8 percent and pulse energies above 10J/liter are obtained. The main mechanism of these productive systems is based on three-body-collisions that are quite frequent at high densities. Molecular ion formations like Ar_2^+ and $ArXe^+$ and subsequent volume recombination with electrons will then occur. The experiments have been performed in the density range of 2 to 5 bar for various discharge powers and e-beam currents. It is observed that during the pulse quasi-stationary operation is obtained. The stationary duration in our experimental regime can be up to 20 μs. It depends on the gas density, discharge power and e-beam current density. An analytic model has been developed which is in good agreement with the observations. The radiation production process is strongly effected by the gas temperature because of the temperature dependence of the ion formation and recombination processes. The quenching of the inversion by the electrons turns out to be the main loss mechanism. From the model we deduced that the fractional ionization i.e. the ratio of electrons and nentals is the determining factor. Experimental results and analytic evaluations will be discussed.

LASER COOLING
AND
ATOM OPTICS

Interference of two Bose-Einstein Condensates

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We analyze theoretically the contrast C of atomic density interference fringes when two trapped Bose-Einstein condensates are released and allowed to overlap. We use three different theoretical descriptions of this phenomenon: the Gross-Pitayevski equation (GPE), the number states (NS) with the integer quantity of atoms in the condensates and mesoscopic states (MS) [1]. In the experimental scheme when condensates are cooled separately C=1 and C=0 in the cases of GPE and NS correspondingly, and C<1/4 in the MS approach. In the second possible scheme when the condensate is formed first and then cut, the GPE approach gives the same result as in the first case, while in the NS and MS approaches the contrast decreases with the increasing of time delay between the condensate splitting and its release events.

The observation of spatial interference of two condensates [2] permits us to check the fundamental theoretical conception of macroscopic wave function corresponding to the broken gauge symmetry. We calculate the contrast of interference fringes using different theoretical descriptions of the phenomenon for two different experimental schemes and show, that they give different results. As in Ref.[3] we start from a second quantized form of the Wigner function

$$W(x,p,t)=\frac{1}{2\pi}\int \exp\left(-i\frac{py}{\hbar}\right)\left\langle \hat{\Psi}^{+}\left(x+\frac{y}{2}\right)\hat{\Psi}\left(x-\frac{y}{2}\right)\right\rangle dy. \qquad (1)$$

In the ideal gas case $\hat{\Psi}(x)=\hat{a}_{\alpha}\psi_{\alpha}(x)+\hat{a}_{\beta}\psi_{\beta}(x)$, where $\hat{a}$ is an annihilation operator, $\psi_{\alpha}(x-d)=\psi_{\beta}(x+d)$ are the ground states particles wave functions in the trapping potentials centered at $\pm$ d, and we suppose that the number of particles $N_{\alpha}=N_{\beta}=N/2$. We have

$$\left\langle \hat{\Psi}^{+}(x)\hat{\Psi}(x')\right\rangle=\sum_{i,k=\alpha,\beta} g_{ik}\psi_i^{*}(x)\psi_k(x'), \qquad g_{ik}=\left\langle \hat{a}_i^{+}\hat{a}_k\right\rangle. \qquad (2)$$

Eqs.(1) and (2) give the interference fringes [3] with the contrast $C=2|g_{\alpha\beta}|/\left(g_{\alpha\alpha}+g_{\beta\beta}\right)$. In the case of GPE approach $\hat{a}_{\alpha,\beta}$ are c-numbers $a_{\alpha}=\sqrt{N/2}, a_{\beta}=e^{i\varphi}\sqrt{N/2}$, where φ is an arbitrary phase, and we obtain C = 1. If in the experiment the condensates are formed independently we can attempt to use for averaging the usual number states (NS) $\left|N_{\alpha},N_{\beta}\right\rangle$. But it gives $\left\langle \hat{a}_{\alpha}^{+}\hat{a}_{\beta}\right\rangle=g_{\alpha\beta}=0$ and interference fringes vanish C = 0. Finally for the description of this experimental scheme we can use the mesoscopic states (MS) introduced in Ref.[1]

$$|\tilde{N}\rangle = \xi_0|N\rangle + \xi_1|N+1\rangle, \qquad \xi_0 = \sqrt{1-W}, \quad \xi_1 = \sqrt{W}e^{i\varphi}, \tag{3}$$

where $0 < W < 1$ is a random number. Using the fundamental reasons the author of Ref.[1] claims that this state is a ground state of the condensate. In the case of two independent condensates it takes the form

$$|\tilde{N}\rangle = \sum_{i,k=0,1} \xi_{i\alpha}\xi_{k\beta}\left|N_\alpha + i, N_\beta + k\right\rangle, \tag{4}$$

and the averaging gives $g_{ii} = \dfrac{N}{2} + W_i, g_{\alpha\beta} = \left(\dfrac{N}{2}+1\right)\xi_{0\alpha}\xi_{0\beta}\xi_{1\alpha}\xi_{1\beta}$. The contrast C achieves maximum at $W_\alpha = W_\beta = 1/2$, when $C = 1/4$. This value is four times smaller, than in the case of GPE approach. The meaning of this result is very clear. Due to the quantum nature of state (3) the quantum fluctuations decrease the contrast.

In the other possible scheme, when the condensate is cooled first, then split and after that with time delay τ released, in the GPE approach C again is equal to $C = 1$ and does not depend on τ. In the NS approach we note, that after splitting the wave function is equal to

$$\Psi(x_1 \ldots x_N) = 2^{-N/2}\left[\psi_\alpha(x_1) + e^{i\phi}\psi_\beta(x_1)\right]\ldots\left[\psi_\alpha(x_N) + e^{i\phi}\psi_\beta(x_N)\right].$$

This state can be represented as a superposition of number states $\left|N_\alpha, N_\beta\right\rangle$ [4]

$$|N\rangle = 2^{-N/2}\sum_{N_\alpha} e^{-i\phi(N_\alpha - N_\beta)}\sqrt{\frac{N!}{N_\alpha!(N-N_\alpha)!}}\left|N_\alpha, N-N_\alpha\right\rangle. \tag{5}$$

Using this state for averaging we take into account, that the energy of state $|N\rangle$ in the case of weakly interacting gas is equal to $E(N) = \frac{1}{2}\hbar\omega\left(N + qN^2\right)$ [1,5], where ω is a trapping frequency, $q \sim a/R$, a is a scattering length and R is a trap size parameter $R = \sqrt{\hbar/m\omega}$. Fulfilling the calculation we obtain the contrast $C = \left[\cos(2q\omega\tau)\right]^{N-1}$, decreasing with time delay at the rate $\tau_0 \sim \dfrac{\sqrt{N}}{\omega}(Nq)^{-1}, Nq < 1$. The MS approach gives the same result. We see, that in this experimental scheme the both NS and MS methods are in qualitative disagreement with the GPE results.

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Squeezed states of matter waves

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Squeezed states of the electromagnetic field are well known in quantum optics. They have been extensively studied theoretically and produced experimentally. Are there states of the massive matter that can be called squeezed states? In order to answer this question the notion of a squeezed state will be introduced with the help of Gaussian wave functions. This generalization enables one to study squeezed states in the most general context.

Quantum Chaos Experiments with Laser Cooled Atoms

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We report on the experimental observation of environment induced decoherence in the quantum delta kicked rotor. Ultracold cesium atoms are subjected to a pulsed standing wave of near resonant light. Spontaneous scattering of photons destroys dynamical localization thereby giving rise to quantum diffusion, which approaches the classical diffusion with an increasing degree of decoherence. This tendency is enhanced by a stronger stochasticity in the underlying classical system. A comparison with theoretical predictions is presented. Also investigated are the dynamics associated with KAM boundaries for finite duration pulses.

Guiding and Trapping a Neutral Atom with a Wire

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A neutral atom with a magnetic moment interacts with the magnetic field of a current carrying wire. The interaction leads to a Coulomb-like $1/r$ potential. Atoms in their *strong field seeking state* move in Kepler-like orbits around the wire. In the quantum domain this system behaves like a two dimensional hydrogen atom (see Fig. 1a).

Combining the field of a current carrying wire with bias magnetic fields one can create a large variety of microscopic guides and traps for neutral atoms in their *weak field seeking state*. Here we discuss two characteristic examples: A 2 dimensional quantrupol created by adding a constant bias field as shown in Figure 1b, and a torus shaped trap created by combining the current carrying wire with a 3-dimensional quantrupol trap shown in figure 1c.

These guides and traps can be miniaturized by nanofabricating thin wires on a surface, the atoms being guided above the surface. Such small guides will be a novel tool to construct surface mounted atom guides which could be the building blocks of atom optical quantum networks.

In our experiments, demonstrating guiding and trapping with a current carrying wire, were carried out in four steps.

- *(a)* In a first step we load the lithium atoms in a Magneto Optic Trap (MOT) which is displaced (typically 1 mm) from the wire used to guide the atoms.
- *(b)* After loading the atoms we shut off the slower beam and the center of the MOT is shifted within 5 ms onto the wire by applying an additional magnetic field. Simultaneously the frequency and intensity of the trapping lasers is set at will. This way we can control the size and temperature of the atom trap before being loaded on in the wire atom guide.
- *(c)* We then switch off the laser light and the MOT magnetic fields and then switch on (typical < 100 μs) the current through the wire and the optional bias magnetic fields. Atoms are then trapped. In the guiding experiment atoms move freely along the direction of the wire.
- *(d)* After a preselected guiding/trapping time we switch off all magnetic fields and switch on molasses laser beams for a short time (typically 1 ms). The fluorescent light of the trapped atoms is imaged on a CCD camera. The fluorescence image reflects the spatial distribution of the atoms.

In general we take pictures from above (looking in wire direction) and from the side (looking on to the wire from a direction orthogonal to the wire). Typical pictures of atoms trapped around a current carrying wire can be seen in Figure 2.

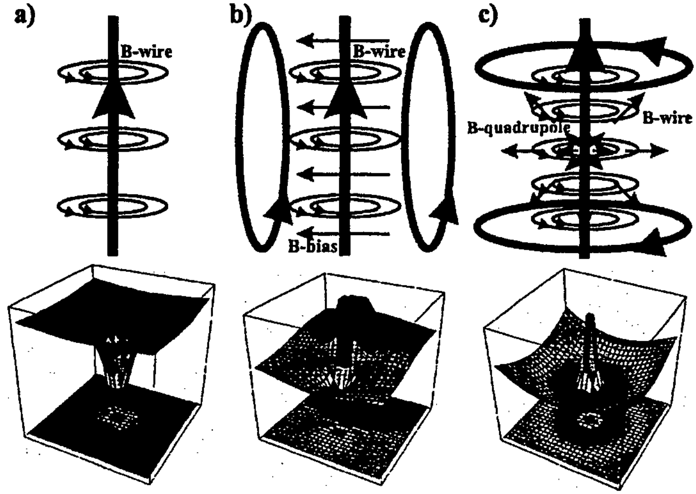

FIG. 1. Three configurations to trap a neutral atom using a current carrying wire. **a)** Trapping the atoms in their ***high field seeking*** state around the wire. **b)** 2 dimensional quadrupol created by adding a constant bias field. **c)** A torus shaped trap created by placing the current carrying wire in the center of a 3-dim quantrupol trap. The field of the wire closes the leak of the quadrupol trap.

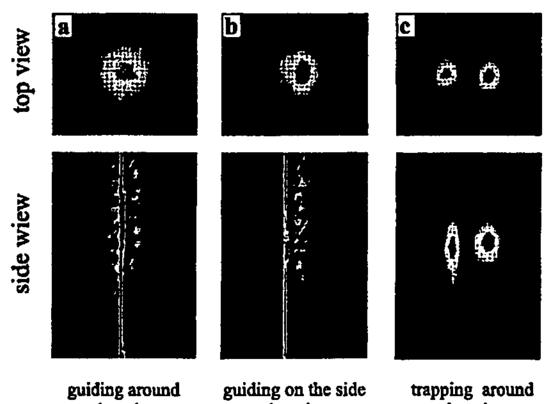

FIG. 2. Experiments demonstrating the guiding and trapping of neutral atoms with a current carrying wire. CCD images of the atoms are shown as viewed from the top and the side. (a) Atoms moving around the wire. (b) Guiding atoms on the side of the wire. (c) Atoms trapped in a combination of a quadrupol trap and the wire magnetic field. The wire was orthogonal to the symmetry axis of the quadrupol, therefore the trap has two minima as can be seen from the top.

Coherence properties of atom lasers at finite temperature

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The attainment of Bose-Einstein condensation (BEC) in dilute, trapped atomic gases [1-3] enhances the prospects for constructing a source of coherent matter waves, or "atom laser." There has been considerable theoretical discussion of the properties of such devices [4,5], and a pulsed prototype device has been demonstrated. [6]

Several essential aspects of atom-laser action have been demonstrated in trapped-atom BECs: first-order coherence of matter waves, as shown by interference fringes in collisions of separately prepared BECs, [7]; and bosonic stimulated scattering, analogous to stimulated optical emission in the kinetics of BEC formation. [8] Ketterle and Miesner [9] have proposed a means of determining second- and third-order coherence functions from measuring release energies and three–body decay rates [10] of BECs, respectively.

The basic theory of coherence has not yet been as fully developed for matter-wave as for optical-wave sources. We are working on a first-principles model of matter-wave coherence in an interacting Bose gas. Our treatment [11] is based on a straightforward application of the quantum field theory of atoms. Although the key result is obtained within the Hartree-Fock-Bogoliubov-Popov (HFB-Popov) approximation [12–15], we believe it will be found to be valid in a wider context. The main messages of our result are as follows.

First, current BEC systems are produced in atom traps, and so they are intrinsically inhomogeneous. Thus, measurements of coherence functions, such as those obtained from release energies or inelastic collision rates, are actually determinations of the average of a local coherence function over an extended inhomogeneous system. Second, the condensed and non-condensed ("thermal") fractions of the atomic gas are distributed differently over

the trap, and they make separate and distinct contributions to the local coherence function. In the HFB-Popov approximation, we find that the local coherence function is related directly to the spatially-resolved condensate fraction $f(\mathbf{r})$ of the gas. For Bose gases with repulsive pair interactions (scattering length $a > 0$), the condensed and thermal components of the gas are largely segregated: the condensate is localized near the center of the trap, from which it expels the thermal cloud by the repulsive interaction. [16] Thus, even for systems that measurements show to have a significant net fraction of thermal atoms, it may be possible to selectively extract an atomic beam with the coherence properties of a nearly pure condensate by using an appropriately designed output coupling scheme.

In particular, we find that the second-order, equal-time coherence function of the atom field, $g^{(2)}(\mathbf{r},\mathbf{r})$, is given by

$$g^{(2)}(\mathbf{r},\mathbf{r}) = 2 - [f(\mathbf{r})]^2, \tag{1}$$

where $f(\mathbf{r})$ is the ratio of the condensate density to the total density at position $\mathbf{r}$. This result agrees in the appropriate limit with that for a homogeneous gas, [17] where f, the condensate fraction, is independent of $\mathbf{r}$; in that case, $g^{(2)}$ is simply a function of temperature T. However, as we have indicated above, in current experiments $f(\mathbf{r})$ depends strongly upon $\mathbf{r}$. Note that $g^{(2)}(\mathbf{r},\mathbf{r}) = 2$ for a thermal gas without condensation and $g^{(2)}(\mathbf{r},\mathbf{r}) = 1$ for a pure BEC; the optical analogues of these values correspond to the phenomena of photon bunching and antibunching, respectively.

Thus, to a large extent, the partially-condensed inhomogeneous Bose gas separates into two components with distinctive coherence properties. This can have a positive impact on atom–laser design. For example, one scheme for out-coupling atoms from a condensate involves focussing two lasers into the condensate to cause transitions between trapped and untrapped magnetic sublevels via a two–photon Raman transition, and can in principle allow beam extraction from specific regions of the trap. Thus, even if one can only generate large condensates at relatively high temperatures, it may still be possible to extract a relatively pure condensate even in the presence of a substantial thermal component of the gas.

Acknowledgements

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Quantum state reconstruction of an atomic matter wave

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Recently much work focused on the reconstruction of quantum states. This new interest grew out of the intriguing possibilities of quantum optics, atom optics, cavity QED, and the physics of trapped particles. There it became possible to design specific quantum states. Hence parallel to this *engineering* of states the question about the measurability of a quantum state has experienced a great renaissance.

Of course it is a basic assumption of quantum theory that an infinite ensemble of systems contains all the information about the corresponding quantum state. But how can we unravel it?

We give a possible answer to this question. In particular we consider the quantum state $|\psi\rangle$ that describes the motional degrees of freedom of a two-level atom in an atomic beam. Our method allows us to measure the wave function $\psi(x) = \langle x|\psi\rangle$ in a simple way. With simplicity we mean that the experimental setup as well as the determination of $\psi(x)$ from measurement data should be as direct and obvious as possible.

Since we can obtain the modulus $|\psi(x)|$ from a position distribution we focus on how to unravel the phase information of the complex quantity $\psi(x)$. We analyze interference fringes in the position distribution after the atom has interacted with laser light and show that this fringes contain the relevant measurement data needed for a reconstruction of the phase. A few interferometric position distributions are sufficient to determine the atomic wave function uniquely.

Applicability and limitations of this measurement method will be discussed by some examples.

Atom Counting

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Recently developed techniques of optical and evaporative cooling make it possible to generate atomic beams of extremely low temperature. These are beams so cold that the atomic de Broglie wavelengths need no longer be small compared to the interatomic distances. Under these circumstances the beams will typically exhibit significant multi-particle correlations of atomic positions and passage times. We discuss different atom counting techniques by which the statistical properties of such beams may be investigated for the case of both bosonic and fermionic atoms, and exhibit examples of the corresponding distributions.

Dependence of the Atomic Scattering in the Field of Counterpropagating Light Pulses on Mode Structure of Radiation

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In this report the scattering of sodium atoms from a beam irradiated (at a right angle) by counterpropagating intensive (~10^3 V/cm) pulses (~10^{-8} s) of resonance laser radiation is studied [1]. Under our experimental conditions, the scattering was caused by the action of the stimulated light pressure on atoms (the gradient force) [2]. The experimental study of the scattering has revealed anomalous frequency properties arising due to the presence of the time delay τ between the counterpropagating pulses. In a typical situation, τ was equal to ~ 10^{-10} sec which value was a small portion of the pulse duration. The anomalous scattering properties manifest itselves in the following: (i) The scattering diagramm (the distribution of scattered atoms over pulses) is asymmetric; (ii) when the resonance detuning increases, the diagramm center of gravity shifts either toward the incident wave (+k) or toward the contrary wave (-k) from the center of the atomic beam). It is shown in [1] that the period of such oscillations is approximately the reciprocal of τ.

Theoretical interpretation [3, 4] of the effects abserved is not yet quite clear and needs further experimental investigation.

In this work, the influence of the spectral structure of the laser radiation on the anomalous frequency properties of the scattering is studied. As a source of radiation we used a pulsed frequency-tunable Rodamin C dye-laser. The laser frequency was tuned near the D_2-line of sodium atom. The measurements were carried out for three laser regimes: the single mode (the spectral width of the laser line was ~ 0.15 GHz), the regime of two-three modes (the full line width was ~ 0.4 Ghz), and the multimode regime (the envelope of the spectrum line was ~1 GHz). The experimental results showed that the scattering amplitude and oscillation period did not depend of the mode spectrum of the scattering field.

Hence, the anomalous frequency properties of the scattering are not related to the time structure of the field which is more complicated for the multimode regime compared to the single-mode one. Furthermore, these results show that the scattering depends on the total intensity of radiation rather than the fields of individual modes; e.g., for the n-mode regime, these fields are by a factor of $\sqrt{n}$ lower than those for the single-mode regime.

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ANOMALOUS COHERENT SCATTERING OF THREE-LEVEL ATOMS IN THE STRONG FIELD OF COUNTERPROPAGATING WAVES

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In the experiments carried out in Ref.[1] on scattering of thermal sodium atoms in the strong resonant field of a standing wave unexpected anomalies contradicting known theoretical representations of coherent scattering of atoms in the field of a standing light wave were observed: an asymmetry of the momentum distribution of scattered atoms and an oscillatory character of the frequency dependence of the scattering amplitude.

It was experimentally established that the given effects are displayed only in strong fields, and oscillations of the scattering amplitude and asymmetry of the scattering diagram occur with an identical characteristic frequency, which does not being a function from neither the field intensity nor the observation angle [1]. A rather unexpected result was obtained: the period of the oscillations is determined by the distance L between atomic beam and the reflecting mirror, i.e., the period is determined by the delay between the incident and reflected from the mirror waves (in the given experiment, the scattering standing wave was formed by two counterpropagating pulses of running waves: incident and reflected from a mirror ones).

A principal explanation of the specified anomalies on the basis of the model of two-level atoms was given in Ref. [2]. Based on the circumstance that the time delay $2L/c$ corresponds to the time when only the incident running wave acts on the atom, a hypothesis was put forward that observed in the mentioned experiment peculiarities may be presumably caused by the state of the atom in the moment of the standing wave establishment, caused by the preliminary excitation of atoms by the incident running wave.

It was shown that, actually, at preliminary interaction with the running wave (provided a sharp inclusion of the interaction), the atom appears in a specific opto-mechanically mixed state for which the ground and excited levels differ on the momentum. Then, it was shown that for the above-stated mixed initial states diffraction of atoms by a standing wave occurs asymmetrically and oscillatory. It was also shown that the value of all the peculiarities are proportional to the amplitude of the field and, consequently, can be prominent only in strong fields.

In the present paper, we first review the proposed model theory of anomalous scattering in the field of a standing wave for two-level atoms.

Then we consider the peculiarities of the anomalous scattering of atoms in the three-level case which recently attracts widespread attention in the context of diverse possible applications in the quantum optics and atomic interferometry.

We examine the opportunities for the development of effective beam-splitters and mirrors, as well as for the achievement of superlow temperatures by the application of coherent speed selection by means of the effective engaging of three atomic levels into the interaction with an external field at anomalous scattering regime. We consider the dispersion of the scattering diagram and snow that the distribution of atoms by momenta at anomalous regime displays essential narrowing of the one of the diagram peaks compared with usual case.

We display the role of new peculiarities taking place in the three-level case (the partial population trapping on certain, populated owing to the preliminary interaction with the running waves, optical-mechanical mixed states, etc.) and show the way the specified peculiarities should be correctly taken into account at choice of an effective modes of atomic selection or splitting of beams by the three-level scheme when applying successive pulses of running and standing waves with non-equal amplitudes, as, for example, at formation of pulse standing fields by reflecting mirrors.

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Atom Interferometry with Cold Atoms

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Progress in the development of high precision inertial force sensors based on atom interferometric techniques with cold atoms will be presented. Using these techniques we have recently demonstrated a gyroscope of ~10^-9 rad/sec/Hz^1/2 sensitivity and a gravity gradiometer with ~10 E/Hz^1/2 sensitivity. We expect further gains in sensitivity with relatively modest modifications to the existing instruments. Future improvements may provide sensitivities high enough for tests of General Relativity. The prospects of using quantum degenerate atomic sources (e.g. Bose condensates) to enhance sensitivity will also be discussed.

Chaotic Bragg scattering

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We study the scattering of an atomic beam slowly passing through a standing laser wave with an amplitude periodically modulated in time. In the far detuned region, the Hamiltonian of the system has the form

$$H = \frac{p^2}{2m} - \frac{\hbar\Omega_{\rm eff}(t)}{2} \exp\left(-\frac{t^2}{\tau^2}\right) \cos^2(kx) , \tag{1}$$

where k is the wave vector of the laser field, x the coordinate of an atom (motion along the wave vector is of only interest), m the atomic mass, τ the passage time (profile of the laser beam is chosen Gaussian), and $\hbar\Omega_{\rm eff}(t)$ is proportional to the laser intensity, which is modulated as $\hbar\Omega_{\rm eff}(t) = \hbar\Omega_{\rm eff}\cos^2(\nu t)$ by using an acoustic-optical modulator. We confine ourselves to a region of system parameters

$$\frac{2\pi}{\tau} < (\omega_{\rm rec}\Omega_{\rm eff})^{1/2} , \quad \hbar' = 4\left(\frac{2\omega_{\rm rec}}{\Omega_{\rm eff}}\right)^{1/2} < 1 , \quad \omega_{\rm rec} = \frac{\hbar k^2}{2m} , \tag{2}$$

which corresponds to the semiclassical adiabatic regime of the scattering [1].

The formal analysis of the problem involves the theory of interacting quantum nonlinear resonances, developed earlier in the field of quantum chaos [2,3]. Two different diffraction regimes are distinguished – a quasiregular regime, where the atoms are Bragg-like scattered by a primary or secondary nonlinear resonance, and a chaotic regime, where the scattering can be regarded as (quasi-)random [4]. These regimes have not been observed before and are of considerable interest both from viewpoints of a physical application in atomic optics and the theory of quantum nonintegrable systems (quantum chaos).

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Design and construction of a high-precision atomic beam machine for quantum optics experiments

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Abstract

We describe an advanced atomic beam setup designed specifically for quantum optics and atom optics experiments. Design, construction, preliminary performance tests and planned experiments are discussed.

We have constructed an atomic beam machine for metastable helium atoms optimized for quantum optics and atom optics experiments. The setup produces a highly collimated, monochromatic (single axial velocity) and intense beam of metastable helium atoms. The beam, exiting from a liquid-nitrogen cooled discharge source, is collimated using transverse laser cooling, Zeeman-slowed to an axial velocity between 100 and 300 m/s, pre-focussed and funneled by two separate 2–D magneto-optic traps. Finally, two 50 μm diameter apertures separated by 2 m are used to bring the transverse velocity spread in two dimensions back to $1-3$ cm/s, corresponding to as low as 0.1 times the single-photon recoil velocity for the $\{1s2s\}^3S_1 \rightarrow \{1s2p\}^3P_2$ two-level transition at 1083 nm. The beam then enters the interaction chamber, where the atoms interact with the quantized light field in an optical cavity, material gratings and/or "classical" light fields. The diffraction of the atoms induced in this region is studied using a position-sensitive metastable atom detector with 50 μm resolution, 2 m downstream of the interaction region. The (far) sub-recoil resolution for the atomic momentum in two dimensions allows us to discriminate effectively between atoms which have or have not spontaneously emitted photons. This information is indispensible when dealing with resonant excitation. The extensive use of laser cooling techniques allows us to obtain a (calculated) flux in excess of 10^4 atoms/s in the final beam. Special attention has been paid to the thermal stability and vibration isolation of the setup and to a clean, hydrocarbon free vacuum. Design, construction and partial performance tests are discussed.

The resulting beam will be used for a variety of cavity QED and atom interferometry experiments. The first experiments which will be performed in the setup are photon number measurements in a high-finesse optical cavity and quantum tomography of atomic (motional) wavepackets. An extension to the setup allows the study of a new type of continuously pumped single-atom laser, operating in the quantized cavity field regime. The system constitutes a true inversionless, two-level, single-atom laser. Its operation is based on the asymmetry between absorption and stimulated emission in a quantized field.

Atom cooling by VSCPT: accumulation plus filtering

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We study the laser cooling by velocity-selective coherent population trapping (VSCPT) in a double-Λ scheme with decay into the outside of working levels. We show that this additional decay channel filters diffused atoms from trapped ones and provides an ultrasharp atomic momentum distribution.

Coherent population trapping was observed for the first time by Alzetta *et al* [1]. This effect is due to the presence of a coherent superposition of the ground states which is stable against absorption from the radiation field. This phenomenon has been exploited in very different applications: metrology, high-resolution spectroscopy, laser multiphoton ionization, four-wave mixing, laser manipulation of atoms, lasing without inversion, and matched pulse propagation.
The application of velocity-selective coherent population trapping (VSCPT) to manipulation of atoms has been studied intensively [2,3]. The basic idea of VSCPT is to pump atoms into a noncoupled state having a well-defined momentum, where the atoms do not interact with the laser radiation. The accumulation of the atoms in this special velocity-selective trapping state is due to spontaneous emission. In the VSCPT experiment [2] performed on ^{4}He metastable atoms, very narrow final distributions of atomic momenta have been observed. The forms and the widths of the momentum distributions have been described theoretically for various schemes and in various regimes [3]. It was common to associate either the peak width or the dark-state population of an atomic momentum distribution with an effective temperature. Based on this effective temperature, it was concluded that laser cooling below the recoil limit has been achieved. However, spontaneous emission produces, not only accumulation of the atoms in the trapping state but also diffusion of a fraction of atoms toward large values of the momentum. Unlike the velocity-selective trapping phenomenon, the diffusion of atoms in the momentum space tends to increase the temperature. Due to such a random process, the wings of the momentum distribution are not of the Gaussian form. In the meanwhile, the wing shape and the fraction of the atoms which have diffused toward the wings are not reflected in the peak width and in the dark-state population. Consequently, the increase of the peak value and the decrease of the width of the final atomic momentum distribution, which is far away from the Gaussian form, do not mean the cooling, and only indicate the accumulation of the atoms in the dark state.

The purpose of this work is to show that one can use VSCPT to perform not, only accumulation but also filtering of atoms in momentum space. Based on the theoretical Λ model of Refs. [2,3], we introduce a double-Λ model, where an additional upper level with possible decay into the outside of the working configuration is added. We find that this new decay channel can filter the atoms in the wings from the atoms near

the peaks of the momentum distribution, and hence laser cooling of atoms below the recoil limit can be achieved.

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DEVELOPMENTS IN ATOMIC STERN-GERLACH INTERFEROMETRY

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The Stern-Gerlach (SG) interferometry was invented by Frisch in the thirties for neutrons and rediscovered more recently for atoms. It is a polarisation interferometry, basically like the optical polarisation interferometer consisting of a birefringent crystal plate set in between crossed polariser and analyser, using the different Zeeman states. Any magnetic field plays the role of the birefringent plate and today, a great deal of static inhomogeneous or pulsed constant profiles had been studied. New investigations include fully time and space dependent fields whose shape move at atomic velocity (comoving fields), a double interferometer configuration and pulsed (non dispersive) Ramsey-like setup.

I. *Comoving fields with $H^*(2s)$ atoms*

By using a set of helices of period λ supplied with alternative currents of frequency ν one obtains a transverse magnetic field of the form $B_0 \cos 2\pi(x - ut) / \lambda\ \hat{y}$, the velocity of which, $u = \lambda\nu$, is easily tuned (by varying ν) to any value below 100 km/s, largely covering the whole distribution of atom velocities [1]. It is easily understood that, for a sufficient number N of periods, the phaseshift $\delta\varphi$ is almost zero for all atomic velocities, except the resonant class $v = u$ for which the atom experiences a fixed field. The device is then highly v-sensitive and, e. g., one can manage to first set the interferometer with orthogonal polarisers and, second, tune the field intensity so that $\delta\varphi=\pi$. The device is then a de Broglie waves filter whose finesse equals to N (fig. 1a). More, one can add up currents of different frequencies to superpose such delta-like transmission and build up any desired dispersion relation $\delta\varphi(v)$. We called "genericity" this ability of comoving fields to create a medium with any dispersion relation. In the end, it must be noticed that the genericity property holds for any comoving refraction index modulation and can be applied e. g. in optics to electrooptic modulators.

II. *A double interferometer with metastable $H^*(2s)$ atoms*

With static fields, $\delta\varphi$ is simply proportional to the atom-field interaction time and the field magnitude B. So, the interference pattern, as a function of the time-of-flight (*tof*), is a sine-type modulation of the roughly Maxwellian incoming *tof*-distribution. On the other hand, as we are using a highly polychromatic source ($\delta v/\bar{v} \approx 1$), the interference pattern, as a function of B, consists of a central and only two lateral fringes (fig. 1b). One can then use a first SG interferometer (I_1) as a prepared source for a second one (I_2). Varying B_2 for a fixed B_1, one should observe the convolution of this

last pattern by the Fourier transform of the modulation induced on the *tof*-spectrum by B_1, that is 3 δ-functions, one centred at 0 and two at values proportional to $\pm|B_1|$. Increasing B_1, ones sees these side bands move away (fig 1b). The basic difference between this experiment and a spin-echo one [2] is readily seen by setting $B_2 = -B_1$ and varying the intensity in the intermediate polariser from zero (spin echo) up to a nominal value for which its operation is complete: no modulation is seen in the first case whereas a super-modulation is observed in the second one (fig 1c). It may be noticed that I_1+I_2 makes the two first step of a quantum Zeno effect.

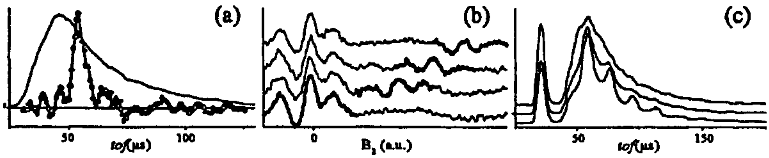

fig 1: (a) monochromator, double interferometer, (b) signal for increasing values of $|B_1|$, (c) effect of the inner polariser

III. Atomic interferometry with a monokinetic potassium beam with chronology control

In a second potassium interferometer, polarisers are SG magnets, the beam spliters are RF antennas and a magnetic profile of overall amplitude B can be scanned in between. A first set of results present the Ramsey fringes and Rabi oscillations patterns in a pulsed regime where the pulse duration is made smaller than the transit time of the atom within each zone. In order to get time of flight analysis of the beam we have varied the delay between the periodic RF pulses (fig. 2a). This technique is shown to work with a slow response time detector. Then we show how by controlling the relative delay between pulses of the RF and of the inner magnetic profile B, it is possible to obtain an analysis of the overall magnetic profile (fig. 2b).

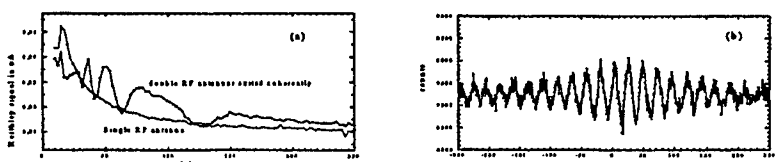

fig 2 : (a) Delay scan with 7μs duration pulses, (b) B pulse (10 μs) gradient scan

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A planar waveguide for atoms

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Planar waveguide structures for ultracold atomic gases are of interest for the investigation of "integrated" atom optical systems like ring resonators, Mach–Zehnder interferometers and the respective atom optical components like right angle pieces, couplers and modulators. On the other hand, if combined with a efficient loading mechanism that provides large pumping rates, lowdimensional waveguide structures are discussed as a possible resonator geometry to realize a cw atom laser [1]. If an atomic source, the atom optical waveguide structure and the detection can be combined on a small area, the analogy to integrated light optics is complete.
In our experiments the planar waveguide for laser cooled atoms consists of a confining potential well created by a far detuned standing light field, which is generated by the reflection of a laser from a metallic mirror surface. The loading mechanism involves evanescent light fields and is therefore able to selectively populate a single well at a distance of a few 100 nm above the surface.
The loading scheme, similar as in [1, 2], is depicted in Fig. 1. We release a cloud of metastable Ar* atoms in the state $1s_5(J=2)$ from a MOT that falls towards a surface under the influence of gravity. The surface is covered with an evanescent, blue detuned light field that hence slows the atoms down. A second evanescent field provides for optical pumping to the $1s_3(J=0)$ state. The transfer probability in this single Sisyphus cooling step is largest at the classical turning point of the motion, where the velocity of the atoms vanishes. Ideally, this point coincides with the minimum of the confining potential. The transfer process thus is selective in real space and momentum space. The decay lengths of the evanescent fields are on the order of the optical wavelength. This leads to the selective population of a single waveguide which is separated by not more than some 100 nm from the surface.
Besides reflecting the waveguide laser we use two other important features of the metallic surface: First, by resonant excitation of surface plasmons in the metal the evanescent braking field is enhanced.

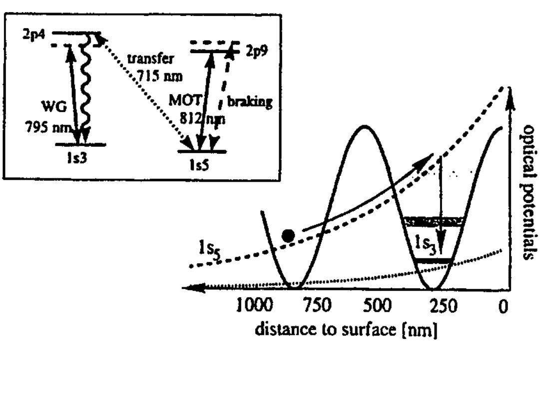

Fig. 1: The optical potentials involved in the loading process: standing light field (solid) and braking field (dashed). The intensity of the transfer laser is also included (dotted line). The inset shows the relevant energy levels and transitions of argon used in our experiments.

Second, upon touching the metallic surface, the metastable atoms produce electrons; this is used to image the atomic spatial distribution through an electron optics onto a MCP/RAE detector.
We typically start with 4×10^6 atoms in the MOT at a density of 2×10^9 cm^{-3}. At the surface, we are left with 1×10^5 atoms at 2×10^7 cm^{-3} within the $1/e^2$ radii of our laser beams of 0.6 mm. We end up with up to 10^3 atoms in the waveguide at a density of 6×10^9 cm^{-3} due to the small volume of the trap. This exceeds the initial density in the MOT and corresponds to a 300-fold increase of the spatial density by collecting the atoms arriving at the surface in the waveguide.
We investigated the lifetime of the atoms in the waveguide. Fig. 2 shows lifetimes as a function of waveguide laser detuning for moderate red detuning. At larger red detuning up to 2.5 nm, atoms are still stored in the waveguide, but tunneling towards the surface becomes the dominant loss mechanism. We also store atoms in blue detuned waveguides without transverse confinement; this restricts the lifetime to about 20 ms.

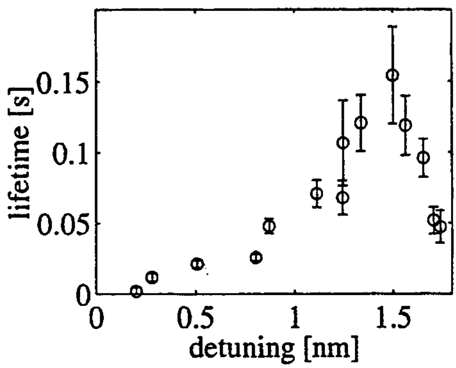

Fig. 2: Lifetime of the trapped atoms vs. waveguide laser detuning at constant intensity. The data is consistent with loss due to light scattering up to a detuning of 1.5 nm, where tunneling losses start to dominate.

The next step in this effort towards high spatial densities in 2D will be to load this waveguide continuously from a magneto-optical surface trap [3], thereby increasing the pumping rates. This 2D waveguide for atoms also provides an excellent basis for studies on "integrated atom optics" in two dimensions. By structuring the waveguide light field an extremely versatile tool can be obtained to study 2D atom optics elements.
This work was supported by the Deutsche Forschungsgemeinschaft (Forschergruppe: Quantengase).

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Longitudinal Atom Optics and Interferometry: half a spin echo

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In contrast to the usual transverse atom optics, longitudinal coherences are intrinsically time-dependent superpositions that require time-dependent means of preparation and detection. A treatment of molecular beam resonance using a quantized (ie. wave mechanical) treatment of the longitudinal motion reveals that resonance regions can entangle the ground and excited internal states with different longitudinal momentum. This has allowed us to create a longitudinal atom interferometer in which longitudinal momentum coherences are created and subsequently detected. The key to this demonstration is the use of separated oscillatory fields with differential detuning. This configuration has the ability to rephase molecules with different velocities in a manner analogous to one half of a spin echo. The ability to detect longitudinal coherences has led to a new method for determining the density matrix. We have measured the density matrix of a supersonic atomic beam.

Experimental Study of Decoherence in Quantum Chaos

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We report an experimental study of decoherence in quantum chaos. Our system consists of ultra-cold cesium atoms in a pulsed standing wave of a far-detuned laser, and is an experimental realization of the quantum kicked rotor. In earlier experiments with sodium atoms we observed dynamical localization, a quantum suppression of classical chaos. The larger mass of cesium relative to sodium greatly reduces the effect of finite pulse duration on the momentum boundary in phase space. We study the effects of external noise and dissipation on dynamical localization of cesium atoms. We observe delocalization as the noise level is increased, approaching the classical limit. The sensitivity to different types of noise and dissipation will be discussed.

New Experiments with Trapped Metastable Helium towards High Densities

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We report about the construction of a new experimental apparatus to trap the isotopes of Helium at high densities. In the future, the new apparatus will serve for studies of ultracold atomic collisions and possible quantum statistical behaviour of the trapped atoms. The collisions between the metastable atoms play an important role for cooling or heating processes in the trapped gas as well as they cause losses of atoms out of the trap and, thus, reduce the atomic density. The atomic beam of Helium is first excited in a cooled discharge source giving a flux of about 10^9 to 10^10 metastable atoms per second. The beam is then collimated and slowed down by optical techniques based on diode lasers, which are amplified with a doped fibre. The atomic beam will be finally loaded into a magneto-optical trap. In the trap we will first investigate the Penning collisions which are typical for metastable rare gas atoms.

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Which-way information in an atom interferometer

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Abstract

We report on the experimental realization of an atom interferometer. By storing which-way information, the spatial interference pattern is destroyed, even though the storing mechanism does not transfer momentum to the atoms.

Wave-particle duality is often used to highlight the difference between quantum mechanics and classical physics. It expresses the fact, that observation of interference and which-way information are mutually exclusive. It has been vividly discussed recently [1], whether the loss of interference in a which-way experiment can always be attributed to mechanical forces. We have performed an experiment, which addresses precisely this question [2].

Our atom interferometer is based on Bragg scattering from standing light waves: A first standing light wave splits the incoming beam of laser cooled Rubidium atoms into two beams of equal intensity. After free propagation, a second standing light wave recombines the beams. A spatial interference pattern is produced in the far field.

In order to obtain which-way information in this scheme, a microwave field resonant with the transition between two long-lived hyperfine ground states of the atom is used. Two pi/2 Pulses of this microwave field are applied, between which the first standing light wave is sandwiched. The effect of the microwave in combination with the standing light wave is, that the internal atomic state will remain unchanged, if the atom is in the transmitted beam, while it will change, if the atom is in the reflected beam. Thus from a later measurement of the atomic internal state it is possible to know the atom's way through the interferometer.

When storing the which-way information, the atomic position distribution in the far field shows no interference fringes. As the recoil of the microwave photons can be neglected, this loss of interference cannot be attributed to mechanical forces during the interaction with the microwave field. Instead, the loss of interference is only due to the entanglement between the atomic center-of-mass motion and its internal state.

By varying the parameters of the experiment, it is possible to store incomplete which-way information. In this case, the two ways are not completely distinguishable. This reduces the visibility of the interference fringes. The experiment therefore allows to observe a continuous transition between the two extreme cases of full visibility without which-way information, and of no visibility with full which-way information.

It is further possible to realize a quantum eraser. For that purpose the internal atomic state is measured projecting onto state vectors that are superpositions of the two atomic ground states, chosen in such a way that no which-way information is obtained. Hence the information is lost in an irrecoverable way. Observing the two subensembles correlated with the result of this internal state measurement, the spatial interference fringes are restored, as discussed in [1].

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Quantum nonlinear optics of solids: hidden integrability, confined gap excitations, quantum gap solitons, soliton pinning, etc.

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It has recently been recognized that the existence of a frequency gap in the spectrum of elementary electromagnetic excitation of a medium (e.g. a frequency dispersive medium, a photonic band gap material or a one-dimensional Bragg reflector) doped with resonance two-level atoms plays a crucial role in optical properties of the medium plus atoms system. Fortunately, the quantum version of the Maxwell-Bloch (QMB) model generalized to the case of a frequency gap medium (FGM) exhibits hidden integrability [1] and is diagonalized exactly by the Bethe ansatz. This gives us a remarkable possibility to find the multiparticle spectrum of the radiation plus medium plus atoms system and to study thus nonlinear optical properties of doped FGM.

Apart from polaritons ("photons in a medium") and their bound complexes ("ordinary" solitons) occurring outside of the gap, the multiparticle subgap spectrum of the system was shown [2] to contain massive pairs of confined "gap excitations", which do not exist out of pairs. Pairs can compose heavy bound complexes ("gap" solitons), enabling the propagation of quantum information within the gap. A gap soliton containing an odd number of excitations is pinned to the impurity atom, realizing thus the effect of multiparticle localization of light in a medium. In addition, the soliton zoo contains "composite" solitons which can be treated as bound states of the ordinary and gap solitons.

In the case of extended atomic system, both gap and composite solitons containing only a few excitations are quite short to propagate without dissipation within the atomic system [3]. They realize thus the quantum self-induced transparency effect in FGM and describe an entirely new mechanism for energy transfer in such a medium. Furthermore, they suggest that a doped FGM with suitable optical pumping may act as a source of novel quantum correlated states of light.

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Fluctuations of the Bose-Einstein Condensate

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The statistical description of a many body system is based on the concepts of statistical ensembles. The theory of Bose-Einstein condensation is usually based on the grand canonical ensemble. This ensemble is known to yield unphysically large fluctuations of the number of condensed atoms. Moreover, the nature of the recent experiments on Bose-Einstein condensation in trapped, dilute atomic vapors is such that after the completion of the final stage of the cooling process, the system is well isolated from the environment both in terms of exchange of particles and exchange of energy. Thus the most appropriate should be the microcanonical ensemble. This last one is notoriously hard to use. Only in the last year the detailed study of the ideal Bose gas in a trap became possible [1]. The most important finding is that at temperatures below the critical one, the excited atoms behave as linked to an unexhaustible reservoir of particles (in the condensate) all at the same energy. We have named the resulting statistical ensemble a Maxwell Demon Ensemble. The open question is the role of interactions. Strictly speaking, it is even difficult to define a condensed fraction in an unambiguous way for the interacting system. To exploit the concept of the Maxwell Demon Ensemble, we propose however, to define single particle Hamiltonian of atoms OUTSIDE the condensate. These atoms do not interact among themselves and move under the influence of the trapping external potential and repulsion by the condensate. Based on this picture, we will present the first results for the fluctuations. Qualitatively, this picture predicts enhanced fluctuations for the condensate fraction as compared to the ideal gas case.

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Subrecoil laser cooling with velocity filtering: Measurement of the waiting–time distribution

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We present the VSCPT laser cooling [1] relied on an open Λ–scheme with the upper working level having an additional channel of decay to a further nondetected level outside the system. A few features of this process are identified: (i) The decay channel acts like a velocity filter ii) The system shows a nonexponential decay law. iii) The counting rate in the decay channel describes asymptotically the waiting–time distribution for the trapping state.

In the total width $\gamma + \gamma_0$ of the upper state, the partial width γ is the rate of spontaneous transitions to the ground state working sublevels, whereas the partial width $\gamma_0 \ll \gamma$ describes the decay to the outside of the Λ-system. In the time domain $t \sim \tau = 1/\gamma_0 g^2 \gg 1/\gamma g^2$ trapping and diffusion processes are described by the kinetic equation

$$\left(\frac{\partial}{\partial t} + \frac{1}{\tau}\right) n_{dif}(p,t) + \delta(p)\,\frac{\partial N_{tr}(t)}{\partial t} = D\,\frac{\partial^2 n_{dif}(p,t)}{\partial p^2}\,, \tag{1}$$

where $g = dE/\hbar\gamma \ll 1$ and $D = (2/3)\,(\hbar k)^2\gamma g^2$. We have neglected the Doppler-shift provided $t \ll \gamma/(g\omega_R)^2$.

The total number of trapped particles is presented as the convolution

$$N_{tr}(t) = \gamma g^2 \int_0^t dt'\, n_{dif}(0,t')\, w(t-t')\,, \tag{2}$$

where $w(t) \sim t^{-1/2}$ is the waiting function [1,2] for the trapping state.

The total number of particles obeys the equation

$$\partial N/\partial t = -(N - N_{tr})/\tau \tag{3}$$

and hence it shows a nonexponential decay law. In the asymptotic time regime, $t \gg \tau$, we have $N(t) \simeq N_{tr}(t)$. This is the result of filtering: The particles which are not in the trapping state populate the nondetected level. Therefore the momentum distribution on the working levels has only two narrow peaks near $\pm\hbar k$ and does

not contain a broad background related to the diffused particles. Moreover we prove that in the asymptotic limit

$$N_{tr}(t) \simeq const. \times w(t) \sim t^{-1/2}. \tag{4}$$

Therefore the counting rate $\Gamma(t)$ in the decay channel

$$\Gamma(t) = -\partial N/\partial t \sim -\partial w/\partial t \tag{5}$$

is proportional to the waiting–time distribution [1, 2]

$$P(t) = -\partial w/\partial t \sim t^{-3/2}. \tag{6}$$

This distribution belongs to the Lévy–law $L_{\mu,1}$ with $\mu = 1/2$.

To conclude, the discussed modell gives a method of direct measurement of the waiting–time distribution for the trapping state.

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Laser cooling of metastable Helium atoms in electric fields

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We discuss our approach to laser cooling and trapping of a high density of metastable helium atoms with the help of electric fields. A dense and cold helium gas is advantageous to perform precision experiments concerning the internal structure of the fundamental Helium atom and is a prerequisite to search for collective effects. Necessary for the achievement of a high density is to minimize severe trap losses due to Penning ionization by trapping spin polarized He atoms.
Only recently, the method of laser cooling and deceleration of atoms in magnetic fields has been applied to cool and trap an intense beam of metastable He atoms produced in a discharge source[1]. Our approach relies on inhomogeneous electric fields for compensating the varying Doppler-shift. In contrast to the Zeeman level shift, which is independent of the principal quantum number n, the Stark shift scales with the seventh power of n. Using a higher excited state as upper level of the cooling transition enables us to compensate for a large Doppler-shift associated with a high initial beam velocity.
In our experiments the metastable He beam is produced in a gas discharge precooled to LN_2 temperature. The mean velocity of the beam is about 1100m/s with an intensity of 10^{14} atoms/sr/s. We use a three stage electrode arrangement with linear field gradients to approximate the field gradient necessary to compensate the decreasing Doppler shift during the cooling procedure. The cooling proceeds on the $2\ ^3S_1$ ($|m|=1$) to $3\ ^3P_2$ ($|m|=2$) transition. Light at 389nm from a frequency doubled Ti-Saphire laser counterpropagates the atomic beam and is linearly polarized perpendicular to the electric field axis. Since the cooling transition is not a closed two level system optical pumping into the $2\ ^3S_1$ ($m=0$) ground state is likely to occur through a cascade decay of the upper level. However, optical pumping has been shown to be ineffective if a small static magnetic field is applied along the beam axis that mixes the magnetic substates of the ground state. A field on the order of the earth's magnetic field is sufficient to sustain the cooling process. Owing to the high polarizability of the 3^3P_2 excited state[2] the necessary electric field strength is around 30-40 KV/cm, which is easily produced in the laboratory and is by far lower than the field strengths used in similar experiments on alkaline atoms[3]. To measure the final beam velocity with a TOF method we chop our atomic beam. Metastable Helium atoms impinge on an ITO coated glass surface transparent for the laser beam, releasing electrons with high efficiency which are accelerated towards a MCP detector. In figure 1) we show typical time of flight spectra with the different segments of our Stark slower subsequently turned on. Fig 1a shows the zero field atomic distribution

slightly modulated by the cooling laser. Figure 1 b), c) and d) show He TOF spectra with the first,

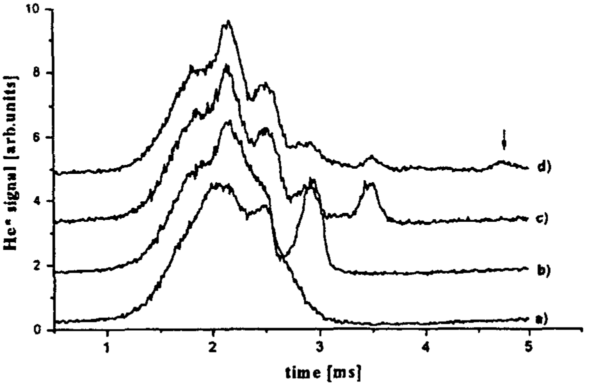

Figure 1: For details see text

the first two and all three Stark segments supplied with appropriate voltages, respectively. Clearly visible is the small peak around 5 ms in fig 1d) (arrow), which corresponds to a final velocity of less than 200m/s. The final velocity thus lies within the capture range of usual magneto optical traps. The spectra are compared to Monte Carlo simulations to obtain details of the cooling process.

Finally, we shall discuss the current status of our experiments using electric fields to trap spin polarized helium atoms.

The work has been supported by the Deutsche Forschungsgemeinschaft.

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Quantum Statistics of an Ideal Bose Gas Cooled by a Thermal Reservoir or, The Laser Phase Transition Analogy and the Bosonic Ground State

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The ground state of an ideal Bose gas consisting of N trapped atoms of temperature T is analyzed. New analytical results are obtained for the statistical distributions, the average number and variance of the number of atoms in the ground state. The present analysis has much in common with the quantum theory of the laser, and with the laser phase transition analogy.

Robust creation of superposition states via stimulated Raman adiabatic passage (STIRAP) with degenerate dark states

by

B. W. Shore, R. Unanyan, M. Fleischhauer, and K. Bergmann

We describe a method for creating an arbitrary coherent superposition of two atomic states in a controlled and robust way by using a sequence of three pulses in a four-state system. The proposed technique is based on the existence of two degenerate adiabatic dark states and their interaction. The mixing of the dark states can be controlled by changing the relative delay of the pulses, and thus an arbitrary superposition state can be generated. It is shown that the method is robust against small variations of parameters (e.g. the area of the pulses) and is insensitive to radiative decay from the intermediate excited state. A time reversed version of the technique makes possible the determination of phase occurring in a superposition of two atomic states.

Thermodynamics of Bosonic Atoms in A Dark Magneto-Optical Lattice

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Abstract

Thermodynamics of bosonic atoms in a dark magneto-optical lattice is considered. It is shown that BEC is possible under laser cooling temperatures.

We present a thermodynamic consideration of possibility of dark magneto-optical lattices for observation of effects associated with quantum statistics of particles. Dark magneto-optical lattices are formed under resonant interaction of a nonuniformly polarized light with atoms under the coherent population trapping conditions (CPT) in the presence of a static magnetic field. Cold atoms being predominantly in the dark CPT-state localize near the points, where these states are not destructed by a magnetic field. As a result the optical interaction tends to zero.

We propose the field configuration for the phase-insensitive three-dimensional trapping of atoms with $1 \to 1$ transition in the dark magneto-optical lattice. It is shown, that in the case of sufficiently strong atom-light coupling the depth of the magneto-optical potential is determined by the ground-state Zeeman splitting $\hbar\Omega$ and the potential period is of the order of the light wavelength λ, in a manner as in the 1-D lattice [1]. If $\hbar\Omega \gg \hbar\omega_r$ ($\hbar\omega_r$ is the recoil energy) the tunneling between the wells is negligible and the lower vibrational level separation is of the order of $\hbar\sqrt{\Omega\omega_r}$. Then if the temperature is less than this value $k_B T < \hbar\sqrt{\Omega\omega_r}$ the quantum statistic effects will appear when the density $n \geq 1/\lambda^3$. Thus, all Bose-atoms, independent of their number, occupy the ground state. There the quasicondensate is formed, when the phase of the atomic wavefunction is determined within the localization distance in a single well ($\ll \lambda$) and randomly changes under transitions between the wells. Since the curvature of the magneto-optical potential in the vicinity of minima is significantly greater than the one in magnetic traps, the degeneracy of an atomic gas will be observable under temperatures $T \sim 10^{-4} - 10^{-6} K$.

Besides, we show that in the Bose case it is possible to achieve Bose-Einstein condensation in a lattice as a whole under the adiabatic reduction of a magnetic field.

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Generic model of an atom laser

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With recent experiments on Bose–Einstein condensation, an atom laser, that is a source for a coherent beam of atoms, has become feasible, and a pulsed atom laser has already been demonstrated [1]. Current theoretical approaches are either based on rate equations [2] or on master equations [3]. In this paper we generalize the Gross–Pitaevskii equation — a mean–field equation that was very successfully used to investigate the properties of a Bose–Einstein condensate — by including gain and loss terms. This model can be regarded as the analog of a semi–classical description of a conventional laser [4] where the electromagnetic field is treated classically.

Our generalization of the Gross–Pitaevskii equation reads

$$i\hbar\frac{\partial}{\partial t}\psi = -\frac{\hbar^2}{2m}\Delta\psi + V\psi + \hbar\kappa|\psi|^2\psi - \frac{i}{2}\hbar\gamma_g\psi + \frac{i}{2}\hbar\Gamma N_e\psi, \tag{1}$$

where V is the trap potential, $\kappa = 4\pi\hbar a/m$ accounts for two–particle collisions, γ_g is the loss rate of the ground state and Γ is the transition rate from the excited state to the ground state. N_e is the number of uncondensed atoms in the excited state that follows from the rate equation

$$\dot{N}_e = R_e - \gamma_e N_e - \Gamma N_e N_g, \tag{2}$$

where R_e models an infinite reservoir of atoms and γ_e is the loss rate of the excited state. For $N_g = \int \psi^*\psi\, d^3x$, the number of particles in the condensate, we obtain from Eq. (1)

$$\dot{N}_g = -\gamma_g N_g + \Gamma N_e N_g. \tag{3}$$

Rate equations similar to Eqs. (2) and (3) have already been discussed in the literature [2]. Above threshold, that is, for $R_e > \gamma_g\gamma_e/\Gamma$, the stationary solution for Eqs. (2) and (3) is $N_g^s = R_e/\gamma_g - \gamma_e/\Gamma$ and $N_e^s = \gamma_g/\Gamma$; the stationary solution of Eq. (1) is the stationary solution of the conventional Gross–Pitaevskii equation for N_g^s atoms in the trap, since the gain and loss term compensate each other.

We have investigated numerically how the system approaches its equilibrium and found that above threshold the number of atoms in the condensate approaches the

stationary solution $N_g^s = R_c/\gamma_g - \gamma_e/\Gamma$. However, in general small collective excitations of the condensate survive since in our generalized Gross–Pitaevskii equation (1) the loss term and the gain term compensate each other when N_g has reached its stationary value. Furthermore, we have introduced a position–dependent loss rate γ_g which in our opinion is more realistic because in experiments the loss occurs mainly at the edges of the condensate. We found that a position–dependent loss rate leads to qualitatively similar results. Additionally, a position-dependent loss rate is able to damp collective excitations.

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Fluctuations in Degenerate Bose Gases

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We investigate the fluctuations in particle-number and phase diffusion of trapped degenerate Bose gases. For the ideal Bose gas we compute exactly the particle number fluctuations of the Bose condensate for various trapping potentials using the microcanonical and canonical ensemble, respectively [1]. Utilizing the recently developed Maxwell's Demon statistics [2], we show that for $N \to \infty$ the root-mean-square occupation fluctuations of the condensate scale $\delta n_0 \propto [T/T_c]^r N^s$ with scaling exponents $r = 3/2$, $s = 1/2$ for the 3D harmonic oscillator trapping potential, and $r = 1$, $s = 2/3$ for the 3D box [5]. We also derive an explicit expression for the scaling exponents r and s in terms of spatial dimension D and single particle spectral index σ, thereby providing a unique classification of trapped Bose gases into different universality classes.

In the second part study the time evolution of the phase of the condensate for (i) an ideal Bose gas and (ii) for a weakly interacting gas. For the ideal Bose gas which is confined by a spatially one-dimensional parabolic trapping potential we extract a quantum mechanical master equation for the ground-state amplitude using a recently proposed model [3] for the cooling of an ideal Bose gas as a starting point. The model displays the expected slowing down of the phase diffusion if the temperature drops below the condensation point [4].

For a weakly interacting Bose condensate we investigate the diffusion of the relative phase for the $T = 0$ ground state of a split condensate [6]. The link between particle number fluctuations and phase diffusion for finite temperatures is indicated using a simplified "flat-bottom" approximation for the particle-number fluctuations [7] (see the talk by K. Rzazewski, Warsaw).

Acknowledgements

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Classical and Non Classical Interference in Phase Space

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Abstract

The relation between quantum interference and classical interference is phase space is discussed in terms of the Wigner function and an analogous classical expression for waves. For two displaced coherent states and two displaced electric field Gaussian pulses, both the quantum mechanical and classical Wigner functions exhibit oscillatory behavior. Wave analogous of squeezing, photon number oscillation, and the Q function are presented [1].

The interference effects are related to the fundamental principle of quantum mechanics: the linear superposition principle. Summation of quantum mechanical amplitudes leads to a wide range of interference phenomena. Wave theory based on Maxwell equations leads to the linear superposition principle for the electric field amplitudes that is the basis of all classical interference phenomena. Both in classical and quantum mechanics the linear superposition principle follows from the linearity of the corresponding wave equations. The fundamental difference between quantum and classical interference is that the particle-wave duality exhibited by quantum systems leads to interference between *probability* amplitudes rather than between physical realities like the electromagnetic waves. This property is reflected in the duality principle. If particle character or the wave character of a system is discussed, quantum and classical systems may exhibit striking similarities. The best example of the wave character is the Young's double-slit experiment either for light or for massive particles.

Interesting features occur when interference phenomena are investigated for a quantum mesosocopic system exhibiting classical behavior. The Schrödinger cat paradox provides an example of such an interference between the two states of the cat. Interference phenomena occur for a system radiating semiclassical fields. The best known example of such a semiclassical field is the coherent state $|\alpha\rangle$ of a single mode electromagnetic field. A superposition of two or more coherent states can exhibit nonclassical effects. The simplest case of such a superposition is given by a linear combination of two "mirror-like" coherent states

$$|\Psi\rangle = \frac{1}{\sqrt{2N}} \left(|\alpha\rangle + | -\alpha\rangle \right).$$

This state, called the even coherent state (ECS), exhibits properties such as the reduction of quadrature fluctuations below the vacuum level and the oscillation of the photon number distribution. The appearance of these nonclassical features of the ECS has been attributed to the quantum interference of the two coherent states.

For large values of the mean photon excitation, $\bar{n} = \alpha^2 \gg 1$, the coherent states represent localized Gaussian wave packets. The natural classical analog of the state

given by ECS is a linear superposition of two spatial wave packets described in 1-D by complex electric field amplitudes

$$E(x) = E_1(x) + E_2(x).$$

This linear superposition of two or more electric fields exhibits classical interference very similar to the interference of coherent states.

In this paper we shall study the relation between quantum interference effects in phase space of the ECS and classical interference of the two electric fields. We shall show that there are similarities between these two types of interference effects. The nonclassical features of the ECS such as squeezing and photon number oscillation will have very simple classical analogies in the framework of destructive interference of classical waves. Although it makes no sense to talk about the Glauber diagonal P-representation for classical waves, it is possible to formulate a Wigner representation for classical waves. Using standard paraxial optics, we shall derive the classical counterpart of the positive Q-representation and show its relation to the interference effects. In this context various wave effects like the Talbot effect [2] or a Fourier transform will be formulated in phase space with the help of the Wigner function.

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PHYSICS OF
SOLID-STATE LASERS

Investigation of chaotic instabilities in mode-locked tunable Cr4+:YAG laser

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We report the results of numerical calculations the steady self-organizing structures of short laser impulses in spatial-temporary phase volume at their nonlinear self-interaction. The optimum configuration of the resonator ensuring reception Kerr lens mode-locking with presence of a strong thermal lens in active media is offered. It is shown, that there is an optimum configuration for Kerr lens ensuring the maximal modulating effect. We investigate of Kerr mode-locked regime in tunable Cr4+YAG laser. We have obtained mode-locked generation of tunable radiation in the range from 1,350 to 1,550 nm. The Cr4+:YAG - laser has consisted of Cr4+:YAG rod placed into the astigmatically compensated, four mirror cavity. The system of pumping with required quality of a zero Gaussian mode for Cr4+:YAG on a basis of the Nd:YAG laser is developed with output power up to 10 W, instability of output power < 0.7 %, instability on a beam angle < 0.03 mrad. Using a 0.5% transmitting output mirror, as high as 305 mW of useful output power at 1500 nm was obtained from the laser with 5.5 W of absorbed pump power. The laser has threshold for mode - locked regime near 7 W for synchronous mode locking and 5 W for active mode locking.

We have analysed the laser system with Kerr lens feedback in the phase trajectory of five-dimensional space. We report the results of computer simulations of chaotic instabilities in modelocked regime in tunable Cr4+:YAG laser. The computer simulations have shown the presence of asymptotically stable stationary point in behaviour of temporal Gaussian beam similar spatial mode structure in the resonators, when the temporal mode does not change passing through all dispersion element in laser. We investigate parameters of resonators for obtaining stable and unstable Kerr lens mode locking. Our calculations show that the sign of dispersion is very important for formation of phase portrait in our laser system. The theoretical investigation of stability mode-locked in laser bring out the criterion of stable operation of laser in Kerr mode locking. The analysis of the solutions in our model reveals that chaotic instabilities can be reached through increasing of non-linear interaction temporal and spatial Gaussian beam.

Long pulse lasing with Q-switching by FTIR shutter.

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Abstract

The results of the experimental study of the Nd- and Er- lasers with frustrated total internal reflection (FTIR) Q-switches are presented. It was investigated the possibility of different types of the laser cavities to generate different shapes of the laser pulses. Special attention was paid to the lasing with long (up to microsecond range) pulses. Computer simulation of the lasing processes was done and demonstrated good agreement with the experiment.

Summery

In this paper we report the results of experiments and computer simulation of the lasing in resonator with frustrated total internal reflection (FTIR) Q-switch. We compared the lasing in two different resonator schemes with Nd^{3+}:YAG being used as active rod. The first type of laser cavity with the length of 60 cm contains output plane and spherical HR mirrors. In the second type all 3 mirrors are HR (Fig.1).

The characteristic features of FTIR-shutter are relatively long switching time (about 0.5 - 1 μs for our Q-switches), extremelly low losses in open position, high damage threshold [1]. Slow switching enables one to enlarge the time duration of laser pulse and to reduce its value of the peak power without efficiency decrease. For practical applications

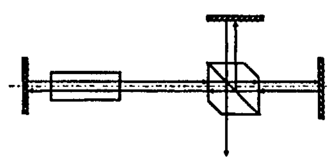

Fig.1

(in medicine for example) it can be important that the amplitude value of pulse power is well below than the damage threshold of fibers, used in apparatus. In the experiment the values of the pumping, the switching time, the diameter of the resonator pinholes, the output coupler in the 2-mirror scheme were varied. To find the optimal parameters of scheme to obtaine the long pulse lasing the computer simulation based on the rate equations system was done. The system was numerically solved for intensity and population inversion for the case of several transvers resonator modes taking part in the lasing. These modes occupy different volume in the resonator, and if the diffraction losses are made different for each of

them, it can be possible to obtain sequential lasing of different transversal modes during the shutter switching. The changes in the diameter of the soft diafragm formed by the FTIR shutter could be taken into account. The pulse duration can achieve the value of the time of shutter switching. But the reducing of the aperture to the size corresponding to TEM_{00} mode makes it impossible to obtain the pulse duration as long as for multimode generation. The efficiency of TEM_{00} lasing is low enough and after the pulse the population inversion in the rod remains high everywhere in crossection except the center.The transverse distribution of population inversion of the Nd^{3+}:YAG crystal can be computed for the different moments of the lasing .

On the Fig.2 the calculated and the experimental laser pulse is shown as a function of time.

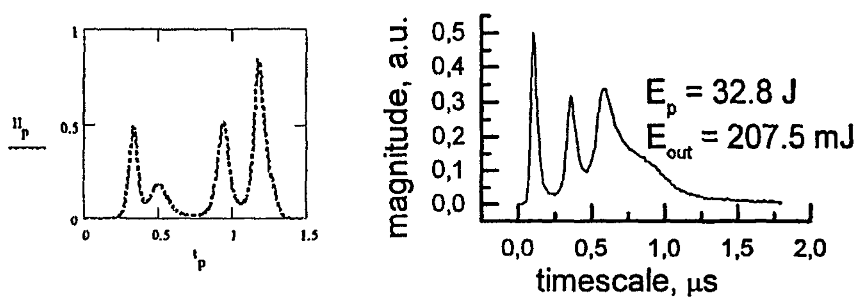

Fig.2

The comparison of this two schemes shows that for 3-mirrors resonator it is necessary to vary the pumping level and pinhole diameter so, that to shift the beginning of laser pulse to the beginning of switching, because the laser emits only till the shutter is not open completely. The pumping in this case should be several times higher than the threshold. For the common, 2-mirrors scheme the efficience of the lasing depends on the output coupler and the generation of the long pulse near threshold is possible. But the efficience of the 3-mirror scheme is higher than that for ordinary one.

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RGB Color Generation via Self-frequency Doubling of Nd doped Yttrium Calcium Oxyborate ($YCa_4(BO_3)_3O$ or YCOB)

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Abstract:

Yttrium calcium oxyborate (YCa4(BO3)3) or YCOB) is a newly discovered phase matchable nonlinear optical crystal with the capability of substitutional doping of rare earth elements. The crystal is congruently melting and large size high quality single crystals are produced by Czochralski pulling. Nd doped YCOB shows excellent lasing and nonlinear conversion efficiency so that self-frequency doubling is feasible in this crystal. We have already demonstrated self-frequency doubling of 1060 nm to 530 nm with 60 mW single mode output when pumped with 800 mW Ti-sapphire laser at 812 nm. Experiment to self-frequency doubling of the 936 nm and 1332 nm lines to 468 nm and 666 nm is underway. We believe that this is the simplest and cheapest way to generate RGB three basic colors.

Timing Jitter Reduction of Ultrashort Tunable Pulses using a Mode-Locked Fiber Laser in Soliton Regime

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Abstract: A stable, passively mode-locked erbium-doped fiber laser is developed to generate tunable pulses in the soliton regime. Estimated rms timing jitter is below 1.8 ps over a 25 nm tuning range, in the offset frequency span of 30 - 3000 Hz.

Summary: Passively mode-locked tunable fiber lasers are attractive ultrashort optical sources for telecommunications and other optoelectronic applications owing to their various excellent properties. However, the generated pulses over a broad wavelength tuning range are not so stable and their production is complex. In this time, we reduced the timing jitter (fluctuations in the arrival time of the pulses) in a passively mode-locked tunable erbium-doped fiber (EDF) ring laser, in soliton regime.

A schematic diagram of the fiber laser is shown in Fig. 1. The pump power from a laser diode is fed into one end of the EDF using a bulk wavelength division multiplexer (WDM). Bulk WDM couplers are used instead of fused couplers to obtain broad band operation. Since the gain bandwidth can be extended by increasing Er concentration and codoping Al, generated pulses is possible over a broad tuning range. The pulse duration of the laser is determined by the total cavity dispersion.[1] A normal single-mode fiber and a dispersion-shifted fiber are included in the cavity to control the total dispersion. These fibers have nonlinear polarization rotation and converts reactive Kerr nonlinearitics into fast saturable absorber action. The nonlinear polarization rotates the polarization ellipse, and the mechanism to a point where higher intensities experience lower loss. Before inserting a band-pass filter (BPF) in the cavity, the waveplates were rotated to obtain mode-locking. The spectral width is 10.6 nm and the pulse duration is 270 fs assuming a $sech^2$ shape at center wavelength of 1.558 μm. By inserting the BPF, the similar repetitive characteristic oscillation is observed. Continuous mode-locked operation from 1.532 to 1.594 μm is obtained by rotating the BPF. The spectral width is 9.3 -10.2 nm for all wavelengths. No adjustment of the pump power and the waveplates was required for tuning.

Phase noise properties are important with respect to applications of the sources. The fluctuations in pump intensity changes the group velocity, the change in the gain profile of the EDF, also changes its index profile. However, owing to the excited states of the erbium ions having long relaxation times, the output pulses is not sensitive directly to the gain fluctuations except at low frequencies.[2] To reduce the intensity fluctuations of the pump source, and to maintain a constant cavity length, it is essential to reduce the influence of airflow and temperature fluctuations. Using an external feedback loop, the intensity is stabilized to within a fluctuation limit of less than 0.1%. Simultaneously, the airflow and the temperature fluctuations in the cavity are closely controlled by using a sealed box with temperature controller. By this controller, the temperature fluctuation in the cavity is reduced to less than 0.01 degrees. Timing jitter is a type of phase noise that can occur in a short time scale. The phase noise in the laser, relative to a radio frequency reference, was determined from the power spectrum of the pulse intensity.[3] To evaluate the timing jitter, we measured the higher harmonics of the noise spectral density. The measurements are made using a fiber coupled, high-speed pin photodiode and a spectrum analyzer.[4] Figure 2 shows the single-sideband noise spectral density, covering an offset

frequency span from 30 Hz to 3 kHz. The upper frequency limit is set by the noise floor and the lower frequency limit is imposed by the resolution bandwidth of the spectrum analyzer. Figure 3 plots the normalized noise against wavelength. The resolution bandwidth of the spectrum analyzer is 30 Hz and the measurement time is 35 ms. The rms jitter is estimated to be below 34 parts in 10^6 of the round-trip time (0.8 ps) at center wavelength, and to be below 86 parts in 10^6 (1.8 ps) over a wavelength tuning range of 25 nm. Since the noise density of the laser is predominated at lower frequencies, it should be possible to reduce the noise by actively controlling the cavity length. The work of G. Ghosh was performed under the management of FESTA supported by NEDO.

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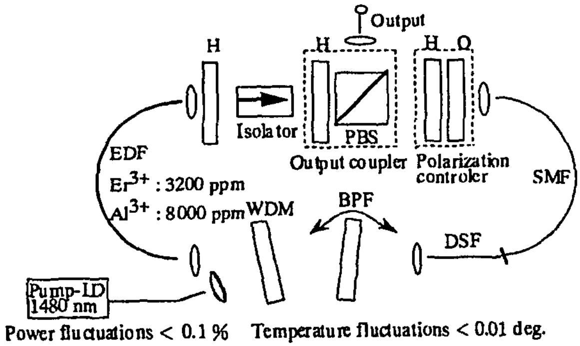

Fig. 1. A schematic diagram of the fiber laser

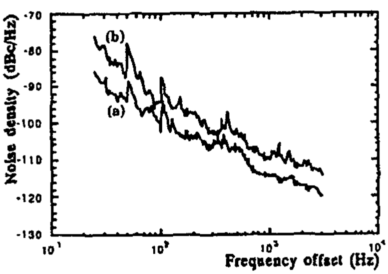

Fig. 2. Single-sideband noise spectral density of the pulse train with a frequency offset from 30 Hz to 3 kHz. (a) 1558 nm (center wavelength), (b) 1572 nm.

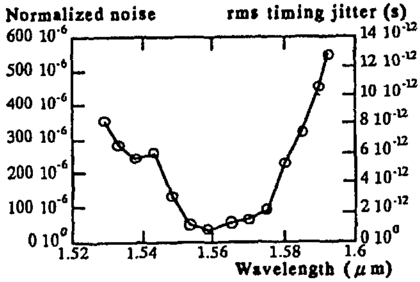

Fig. 3. Normalized noise and timing jitter against wavelength, covering an offset frequency span from 30 Hz to 3 kHz

Low Threshold 100 μs 1.19 μm Operation of a LiF:F_2^- Laser
Pumped by a YAG:Nd^{3+} Laser

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The low-threshold (about 8 W) 100 μs oscillation is reported of a LiF:F_2^- laser pumped by a YAG:Nd^{3+} laser (λ=1.064 μm). The electronic negative feedback loop enables pumping in the form of spikes-free 80 μs pulses and oscillation of similar 70 μs pulses by the LiF:F_2^- laser at wavelength 1.19 μm.

Tuning cw operation of a LiF:F_2^- laser (range 1.1-1.26 μm) at room temperature is of great interest because of its practical applications. However, up to now only quasi-cw operation of a LiF:F_2^- laser was achieved at repetition rate from 1-20 kHz at pumping by pulses with duration less than 1 μs [1]. There are some problems which should be solved to achieve this goal. We single out two of them: 1) oscillation threshold (which have to be done low enough, at least in the range of several Watts, in the case of cw operation), 2) strong thermal lens which arises in a LiF:F_2^- crystal under the action of pumping and as a result of oscillation quenching [2,3] (this problem may be removed by a proper design of LiF:F_2^- resonator [2]). The pump power threshold P_{th}=10 W has been reported [1] for pumping a LiF:F_2^- laser at λ=1.047 μm (pump pulse duration of 1000 ns) and that of 100 W for pumping at λ=1.064 μm (pump pulse duration of 200 ns). The fresh results [1] are the best known to date. It should be also mentioned the outstanding results [3] (P_{th} =2.3W for the cw mode of LiF:F_2^- laser), which have not been repeated up to now.

In the present work, we report LiF:F_2^- laser oscillation at pumping by a YAG:Nd^{3+} laser (λ=1.064 μm), with pulse duration of about 100 μs. The YAG:Nd^{3+} laser had negative feedback electronic loop enabling the laser to emit spikes-free 80 μs pulses. The LiF:F_2^- active element length was 2.5 cm and had initial transmission T_0=40%. The collinear scheme of pumping was implemented. Pulse repetition rate was up to 5 Hz, so average pump power was low and thermal lens negligible.

Fig.1,*a* shows pump power at the incidence plane of LiF:F_2^- crystal as function of time. Output power of the LiF:F_2^- laser (λ=1.19 μm) versus time

is presented in Fig.1,*b*. The traces in Fig.1 *a,b* are obtained with a digital oscilloscope TDS 744A. Vertical axes in Fig.1 are calibrated in Watts.

To find out the value of threshold, we have calculated output power P as function of pump power P_p by using expression $P(\eta, P_P, P_1) = \eta \cdot P_P - P_1$, where η is the slope efficiency. The parameters η and P_1 have been found by minimising the function $F(\eta, P_1) = \sum_i (P_{0i} - P(\eta, P_{Pi}, P_1))^2$, where P_{0i} and P_{Pi} are the experimentally measured output and pump powers and index i runs from 1 to 500 (see Fig.1). The calculations have showed that $F(\eta, P_1)$ has minimum at η=5.7% and P_1=0.46W. In Fig.1,*b*, the dashed curve is calculated one with these values η, P_1. Knowing η and P_1 ,one can calculate the threshold value ($P_{th}=P_1/\eta$), which is occurred to be 8.2W.

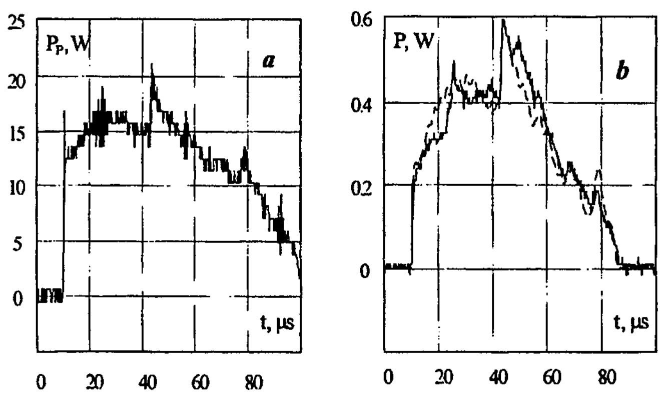

Fig.1. Pump power at the input face of LiF:F_2^- (*a*) and output power of the LiF:F_2^- laser (*b*) (solid lines) as function of time. Dashed curve (*b*) is output power calculated on the base of pump one (*a*), with η=5.7% and P_1=0.46W (P_{th} = 8.2W).

We believe that such a mode of pumping is a transition to the cw case. The research was supported by the Russian Fund for Basic Research (Projects ## 96-02-18827, 97-02-17247).

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Singly resonant sum frequency mixing of two Nd^{3+} lasers in periodically poled lithium niobate

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Abstract:

We present a method of generating coherent radiation in the orange to red spectral region from a singly resonant sum frequency mixer. The mixer consists of a 6mm periodically poled lithium niobat nonlinear crystal inside a high finesse 1080nm Nd:YAP laser. The nonlinear crystal is seeded by a polarized 1444nm Nd:YAG laser to generate radiation at 618nm. At 670mW seeding power, up to 186mW of radiation at 618nm were generated, equal to 28% conversion. A beam quality of M^2=1.1 of the 618nm radiation and a temperature tuning bandwidth of 6.0K were measured and several combinations of beam foci inside the nonlinear crystal were investigated. Momentarily, the output power of the mixer is limited by beam degradation of the 1080nm Nd:YAP laser, probably induced by intensity dependent mechanisms in lithium niobate.

Summary:

Recently, several authors reported on new techniques of generating coherent radiation in the orange-red spectral region around 600nm[1-3]. Those wavelengths are of special interest for medical applications (photodynamic therapy), display technology and other. Very recently, 2.5W of nearly diffraction limited radiation at 629nm where presented by implementing periodically poled lithium niobate (PPLN), showing the possibility to obtain powers above 1W[4]. Unfortunately, long term stability problems were observed and relatively small spectral bandwidths for pump lasers were required (<0.01nm).

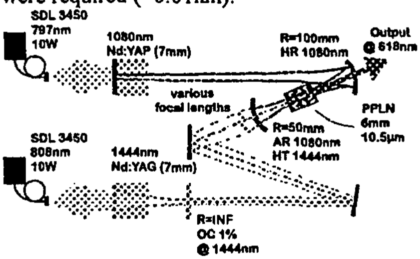

Figure 1: Singly resonant sum frequency mixer

In our approach two longitudinally diode pumped lasers, a Nd:YAG laser at 1444nm and a Nd:YAP laser at 1080nm are sum frequency mixed inside a PPLN crystal. The setup is shown in Figure 1. The 1080nm laser was pumped by a 10W fiber coupled diode module (SDL, 792nm) and produced, using a 3% output coupler, 2.2W output power at 1080nm without, and 1.35W with the PPLN crystal inside the cavity. Substituting the output coupler with a highly reflective mirror (R~99.98%), output powers of 16mW with intracavity beam aperture (M^2=1.1) or 33mW without aperture (high transversal modes) were measured. They indicate intracavity powers of roughly 80W TEM_{00} or 165W at multi transvers mode operation. These powers are small compared to what was expected. We assumed this might be a result of intensity dependent loss or distortion mechanisms in PPLN already

observed in other experiments[4,5]. The three mirror resonator of the 1080nm Nd:YAP laser generated a 60μm beam waist at the nonlinear crystal. Its spectral bandwidth was measured as 0.35nm. The 1444nm Nd:YAG laser consisted of a 65mm plan parallel resonator and was also pumped by a 10W fiber coupled diode module (SDL, 808nm). The 7mm laser crystal required a special laser coating for operation at 1444nm. The end coating was highly reflective for 1444nm and additionally highly transmissive at 1360nm-1320nm and 1064nm (T_{1360nm}>50%; T_{1064nm}>95%) and the other coating was highly transmissive at 1444nm and 1064nm. The laser was polarized by introducing a 150μm thick glass plate at Brewsters angle inside the resonator. From this setup up to 700mW at 1444nm with an M^2=1.1 and a spectral bandwidth of 0.35nm were achieved. The radiation from this laser was focussed through the endmirror of the 1080nm Nd:YAP laser into the PPLN crystal. The PPLN crystal had a length of 6mm and an aperture of 0.5mm x 3mm. The crystal was poled at Stanford University and had a grating period of 10.5μm. The theoretical spectral- and temperature acceptance bandwidths of this crystal are 0.67nm and 5.1K. The crystal was mounted in an oven and was held at a stabilized temperature of 136°C to achieve phasematching and to avoid gray tracking inside the niobate crystal. The end surfaces of the PPLN were anti reflection coated for 1080nm and 1444nm.

Several focus diameters for the seed laser were investigated. Even though a theoretical model on singly resonant sum frequency mixing has been proposed[6] it is not explicit on optimized beam waists. However, it was observed that focussing to a beam waist roughly matching the optimum condition for second harmonic generation predicted by Ref.7 resulted in highest output powers. With a beam waist of 30μm, coherent radiation of 186mW at 618nm with an M^2=1.1 and a spectral bandwidth of 0.08nm was measured. The conversion efficiency from 1444nm radiation to 618nm radiation is 28%. By relpacing the R=100mm folding mirror of the Nd:YAP resonator with a R=50mm mirror, the 1080nm radiation beam waist inside the PPLN was reduced to 34μm. Even though this should have increased the output power according to Ref. 6 , it was decreased. The intracavity intensities of the 1080nm YAP laser with this setup were even smaller than before and resonator stability was reduced. This is a further indication for the loss mechanisms mentioned above. All results are shown in Table 1. The temperature dependence of the mixing process was measured. A tuning bandwidth of 6.0K was observed. This is in reasonable agreement to the theoretical value for mixing single frequency radiation (5.1K). The noise was measured over a time scale of several tens of seconds. The rms noise of the generated sum frequency output power is smaller 1%.

In conclusion, we demonstrated a new resonator design for generation of coherent radiation in the orange to red spectral range. So far, 186mW of radiation at 618nm were generated with this setup. The beam quality was nearly diffraction limited and the rms noise was smaller 1%. It was found that the limiting factor was the beam quality reduction of the 1080nm laser exposed at higher intensities within the PPLN crystal. This will have to be further investigated. In principle, this mixer could generate many other wavelengths, by simply exchanging the seed laser and by using a different poling period crystal.

beam waist 1444nm laser	beam waist 1080nm laser	output power at 618nm
17μm	60μm	56mW

23μm	60μm	164mW
30μm	60μm	186mW
48μm	60μm	117mW
30μm	34μm	~100μW

Table 1: Various combinations of fundamental laser beam waists

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Water-cooled Yb:YAG disk laser pumped by a stacked diode array

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Abstract

A pumping scheme to transform an astigmatic beam into a stigmatic one was designed. With this set-up the output power of a stacked diode array is turned into a radially symmetric beam and then focused into an axially cooled disk laser to serve as a pump source.

Summary

The major advantage of thin disk lasers compared to rod lasers is the reduction or even absence of thermal effects as thermal lensing, stress birefringence and other aberrations. Due to this fact the volume of the fundamental mode is only limited by the resonator design. Matching the pumped volume to the TEM00 volume of the resonator - or vice versa - will lead to efficient fundamental mode radiation.

To the authors knowledge such disk lasers have only been pumped by fibre coupled laser diodes so far. This results in high nominal optical to optical efficiencies as the losses of coupling the diode power into the fibre is omitted. These losses as well as the bad beam quality of the laser diodes limits the power available at the fibre end. To scale the pump power of the disk laser several pump fibres have to be used and therefore the resultant beam quality of the pump source is reduced.

Stacked diode arrays offer a high output power at high efficiencies. The major disadvantage of the stacked arrays compared to fibre coupled laser diodes is the reduced ream quality and the astigmatic beam profile. To overcome the problem of astigmatism a beam transformation optic has been designed to turn the beam emitted from the stacked diode array into a radially symmetric one. With this pumping scheme disk lasers with Nd:YVO4 and with Yb:YAG crystals have been realized.

High Power Nd:YAG Laser with birefringence compensation and adaptive HR-mirror

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Abstract

A dynamically stable resonator with a birefringence compensated two-rod Nd:YAG-System has been designed. The stability of the resonator is controlled by an adaptive end-mirror. With this laser an average output power of 128 W at a beam quality of 0.45 mm mrad (M^2<1.5) has been realized.

Summary

Radial/tangential birefringence due to thermally induced stress is a common problem of Nd:YAG rod lasers operating in the range of more than 30 W average output power. The birefringence leads to depolarization and hence increases losses of polarized lasers. The effect of bifocusing - going along with the thermal birefringence - causes different stability ranges for radially and tangentially polarized light in the laser resonator. Both essentially limits the fundamental mode volume in lasers operation at moderate pump power.

A birefringence compensated pulsed Nd:YAG laser system using an adaptive HR mirror as back mirror of the resonator has been designed and investigated. This laser consists of a two rod system where the principal planes of the thermal lenses of the rods where imaged onto each other by a telescope. A 90° quartz rotator between the rods swaps radial and tangential polarization and therefore enables the second rod to compensate for the radial/tangential birefringence of the first rod.

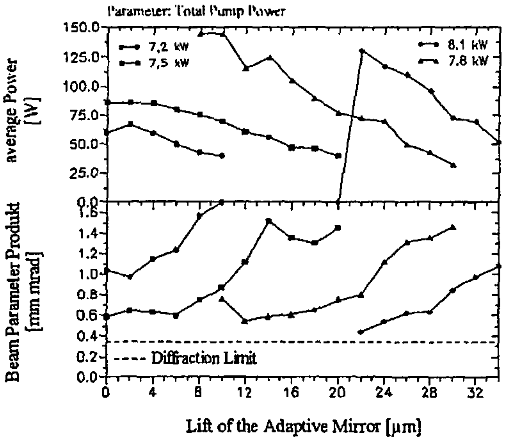

Fig. 1: Output power and beam parameter product as a function of the lift of the centre of the adaptive Mirror.

With this system an average output power of 146 W at a beam quality of 0,7 mm mrad (half angle · radius, $M^2 \cong 2$) and an average power of 128 W at a beam quality of 0,45 mm mrad ($M^2 < 1,5$) have been realized at a repetition rate of 150 Hz. Drilling experiments on titanium (thickness: 1mm) show that a third of the pulse energy at this beam quality would last to drill a hole with a single shot, i.e. using diffractive optics splitting the beam into three beams of the same power 450 holes cold be drilled per second.

The influence of a local refractive index profile on transverse modes in stable resonators

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Abstract

Due to the dependence of the refractive index on the temperature and the inversion of an active medium in an end-pumped solid-state-laser a local refractive index profile is induced at the position of pumping. The overlap of this refractive index profile with the transverse modes is different for each mode index, thus the transverse structure and the frequencies of the modes are changed in a different manner. In that paper a method is introduced obtaining the mode structure and the frequencies of transverse modes in existence of a local refractive index profile.

Summary

In the standard theory the transverse modes are obtained as a solution of the wave equation or as an eigensolution of the Kirchhoff-integrals for the round trip propagation within a resonator [1]. Optical elements are adapted to these free-space modes with the help of the ABCD-matrices. The beam size and the phase-fronts are matched to the resonator configuration by choosing q-parameters which are eigensolutions of the ABCD-matrix.

In end-pumped solid-state lasers a local refractive index profile occur in the laser crystal at the position of pumping. The thermal lens and the inversion profile produce a local refractive index profile which has different influences on the transverse modes for each mode index. Hence the influence of a local refractive index profile on transverse modes cannot be described by ABCD-matrices which would give the same result for each transverse mode.

A simple method is presented to calculate the influence of a local refractive index profile on transverse modes. The index profile is assumed to be a two dimensional Gaussian variation. The amplitude, the width and the position relative to the optical axis of that Gaussian profile are variable. The eigenmodes of the resonator are obtained from a matrix method based on wave expansions. The propagation within the resonator and the phase shift at the curved mirror are described by matrices. These matrices form a round-trip matrix whose eigenvectors give the transverse eigenmodes of the resonator and their frequencies [2]. To include the local refractive index profile into the description the matrix method is extended by an additional matrix.

The eigenmodes and their beat frequencies are investigated. The beat frequencies are changed depending on the mode index and on the position of the refractive index profile relative to the optical axis. Additionally the change of the beat frequencies as a function of the power of the refractive index profile is studied. The change of the frequencies is in the order of several MHz for an index profile with an amplitude of $2\pi/100$ and a width equal to the beam waist of the fundamental mode.

The results of these studies are important in end-pumped solid-state lasers. The effect of different changes of the beat frequency for different transverse modes has to be considered in experiments in which the coupling of transverse modes is required [3, 4].

This work was partially supported by the Herbert-Quandt- Stiftung of the Varta AG.

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A Novel Modeling for KLM Solid State Laser Resonator

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Abstract

A novel "thick-lens" model for Kerr lens mode-locked solid state laser resonator is present. With the "thick-lens"-like matrix formalisms the cavity mode modulation outside as well as inside the laser rod can be calculated. Criteria for the design and optimization of the resonator with hard or soft aperture are predicted efficiently.

Kerr lens mode-locking (KLM) is the dominate mechanism to generate ultrashort optical pulses in solid-state lasers and has been extensively studied. Several theoretical models such as the thin lens model and distributed lens model have been developed to analyze the optical mode modulation in the lasers.[1,2] Since the reported nonlinear matrixes of the models are the extension of linear matrixes, the elements of the nonlinear matrix are dependent of the beam power and the beam parameters . It is known that this kind of matrix (with elements dependent of the beam parameters) is not unique and will cause the problem of solution ambiguity of the "ABCD " law. In this letter we propose a "thick lens" model to describe the effects of self-focusing in the laser rod. a finite thick Kerr medium. The transfer matrix of a gaussian beam propagating through the Kerr medium, MK, can be expressed as

$$M_K = \begin{pmatrix} 1 & 0 \\ -n_0(n'-1)/n'R_o & 1 \end{pmatrix} \begin{pmatrix} 1 & L/n_0 n' \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ n_0(n'-1)/R_i & 1 \end{pmatrix} \qquad (1)$$

where R_i and R_o are the curvature radii of the beam at the input and output surface of the Kerr medium, respectively. n_o and L are, respectively, the refractive index and the length of the medium. The nonlinear scale$n' = 1/\sqrt{1 - P/P_c}$, P is the beam power and P_c is the critical power for self-focusing. Eq. (1) expresses a "thick lens"-like matrix which consists of two curvature radii of -R_i /[n_o(n'-1)] and R_o /[n_o(n'-1)] and a thickness of optical length of L/n'n_o . The thickness and curvature radii of the "thick lens" are dependent of the beam power and the beam curvature radii at the input and output surface of the medium but independent of the beam parameters inside the Kerr medium. For beam power 0¡P¡P_c, n'¿1, the thickness and the curvature radii of the "thick lens" decrease in comparison with that for P=0, n' = 1. These phenomena represent the self-shortening and self-focusing. When the beam power P = 0, n' = 1, Eq. (1) reduces to a transfer matrix of a homogeneous medium. As P¿P_c , n' is imaginary, the transfer matrix of Kerr medium losses its physical meaning. The beam is (ideally) focused into a point (vanishing spot size) inside the medium. If P approaches P_c, $n' = \infty$, Eq. (1) reduces to unity implying that the beam is self-trapping. It is interest to point out that the transfer matrix expressed in Eq.(1) is usually asymmetric and direction dependent. For a counter-propagation gaussian beam the

transfer matrix of the Kerr medium is the inversion of that expressed in Eq.(1). Also the elements of the matrix are unique for certain beam power. These are more convenient for the calculation of the beam parameters with the "ABCD" law.

As an illustrative example we analyze a standard astigmatic compensated resonator of KLM Ti:sapphire lasers. The resonator consists of a Ti:sapphire rod, two focusing mirrors and two flat cavity end mirrors M_4 and M_3. The self-consistent curvature radii of the gaussian beam on the two surfaces of the medium, S_1 and S_2 , are R_1 and R_2, respectively. The transfer matrix for a gaussian beem propagation from M_4 to M_3 is the product of the linear matrixes for propagation from M_4 to S_1 and from S_2 to M_3 and the nonlinear matrix for propagation from S_1 to S_2. Using the ABCD law, the self-consistent spot size at the two cavity end mirrors, w_3 and w_4, can be obtained as that for a linear resonator:

$$w_4{}^4 = -(\tfrac{\lambda}{\pi})^2 \tfrac{DB}{CA}, w_3{}^4 = -(\tfrac{\lambda}{\pi})^2 \tfrac{AB}{CD} \tag{2}$$

where A, B, C and D are the elements of the combined "ABCD" matrix over a round trip of the resonator. The curvature radii R_1 and R_2 are the functions of w_4 and w_3, respectively, $R_1 = R_1(w_4)$, $R_2 = R_2(w_3)$. Combining these two equations with Eq. (2), the values of R_1, R_2, w_3, w_4 can be calculated. A detail calculation shows that as the resonator works in the vicinity of the stable cavity limits (where $A = 0$ or $D= 0$), the relative variation of the beam spot size α has larger value and the "thick lens" appears more asymmetric. This indicates that as one of the two surfaces of the Kerr medium is set at the waist of the gaussian beam in the subcavity (formed by the two focusing mirrors) for lower beam power, an extreme value of α at the end mirror M_3 or M_4 can be obtained. KLM can be started and maintained more effectively with hard aperture.[3]

In conclusion, self-focusing in a Kerr medium can be described by a "thick lens" model which gives a clear physical insight into the analysis and design of a KLM laser resonator and provides a simplified calculation of the cavity mode modulation even inside the Kerr medium in where the beam parameters are hardly possible to calculate with other model.

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Status of the National Ignition Facility Project

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ABSTRACT

The National Ignition Facility (NIF) for Inertial Confinement Fusion will produce 1.8-MJ, 500-TW pulses from a 192-beam frequency-tripled, neodymium-glass laser system for exploration of fusion ignition and other problems in high-energy-density physics. NIF is now under construction at Lawrence Livermore National Laboratory .Status of the National Ignition Facility Project

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SUMMARY

Construction of the NIF facility began in July,1997. The first 8-beam array will be installed by September 2001, and the first 48 beams will be available for target experiments in September 2002. The project will be officially completed in September 2003 with 96 beams available for target experiments the remaining 96 beams installed and in the process of activation.

The National Ignition Facility (NIF) is required to routinely deliver 1.8-MJ pulses at 350 nm with peak power of 500 TW, shaped appropriately for ignition targets. The laser for this facility will be a multipass neodymium glass laser containing 192, independent, 40x40-cm-aperture lasers arranged in 24 modules, each an array of 8 beams -

four high and two wide. To maintain high cleanliness, components will be assembled in cleanrooms, transported to the laser bay in sealed, clean containers, and loaded into the laser support structure from the bottom. Each individual laser beam will be essentially identical to the existing Beamlet laser testbed at LLNL, thus giving high confidence in performance capabilities. NIF requires 7500 optics of 40-80 cm2 dimensions and 30,000 smaller optics. Required production in a four year period greatly exceeds current production capacity. Recent development projects to address this issue include work by Schott Glass Technologies and Hoya Corporation on continuous melting of neodymium-phosphate laser glass, and extension of work begun at Moscow State University on fast-growth of KDP and DKDP crystals to produce 57x57x47 cm3 crystals at growth rates of 10-20 mm per day.

NIF's target chamber will be a 10-m-diameter aluminum sphere, lined with boron carbide plates forming a protective "first wall". The KDP crystals, used for harmonic generation, as well as all other final optics will be located in the target vacuum chamber. NIF also will use a diffractive, "color-separation" gratings on each beam to divert r
esidual first- and second-harmonic light away from the target, rather than relying upon color dispersion in the focus lens to accomplish this function as done on Nova. These features minimize thickness of the third-harmonic optics, thus permitting generation of short pulses with higher peak power, as requested by user groups.

Measurement of the nonlinear absorption coefficients of KTP crystals in the green spectral range

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Abstract:

The absorption coefficients of nonlinear crystals for the fundamental and second harmonic wave of Nd:YAG lasers are the all-decisive parameter for high average power second harmonic generation. A proven method to measure low absorption coefficients is to use an interferometric laser calorimeter with high power lasers [1].
Numerical results have shown that specially for KTP crystals there are deviations between theoretical and experimental results that could be explained by a nonlinear absorption coefficient in the green spectral range [2]. Therefore the well known experimental setup was extended for the measurement of the intensity of the green laser beam as shown in fig.1.

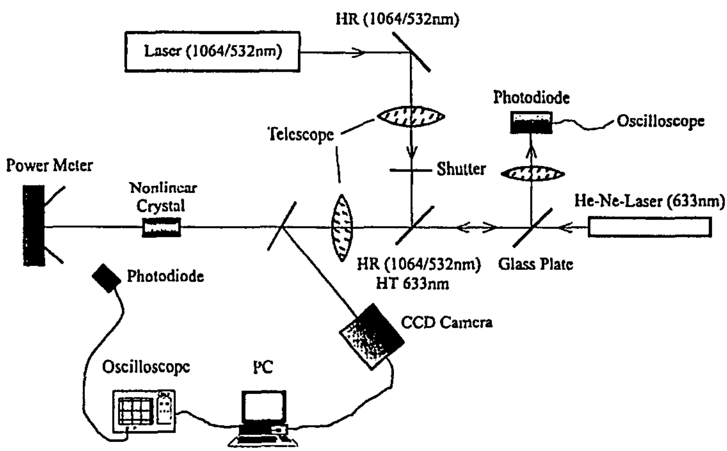

Fig. 1. Experimental setup

The intensity was adjusted by variation of the repetition rate and the pumping power of the cw-pumped actively Q-switched internal frequency doubled Nd:YAG laser. The average intensity was determined by the measurement of the beam profile and the shape of the laser pulse for every absorption measurement.
Two different KTP crystals from different manufacturers were measured for two polarization directions in the green spectral range. The results show that the absorption coefficient of KTP in the green can be described in the form:

$$\alpha = \beta + \gamma I$$

for averaged intensities I in the range from 0.1 to 1.2 MW/cm^2 where β is the linear absorption coefficient and γ is the two-photon absorption coefficient [3]. Higher intensities were not used to avoid damage of the crystal that appear at this order of magnitude due to the use of long pulses (up to 500 ns) in the green and the peak intensity. The most probable reason for the nonlinear absorption coefficient is the existence of a two-photon absorption process in the KTP crystal [3].
The poster will present the measurement method and the experimental results in detail.

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7th International Workshop on Laser Physics (LPHYS'98),Berlin,Germany, July 6-10,1998

Highly Efficient Thermal-Birefringence-Compensated Laser-Diode Pumped Solid-State Laser with High Beam Quality

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Abstract

A new laser-diode (LD) pumped eight pass 1064-nm Nd:YAG zig-zag slab laser amplifier architecture [1] is proposed and the energy extraction performance has been experimentally investigated. High energy extraction efficiency of upto 73% has been achieved with thermal birefringence compensation. The eight pass amplifier consists of a Nd:YAG slab (4mm x 8mm x 35mm),a Faraday rotator, thin film polarizer, five high reflection mirrors, a 90 degree qualtz rotator for thermal birefringence compensation and a quarter-wave plate. The input laser pulse (31ns FWHM,0.55mJ) to the amplifier, which is 2mm in diameter and p-polarized to the polarizer, can pass through the amplifier slab for 8 times. The amplified pulse (26ns FWHM,24.9mJ) is finally extracted by the polarizer. The amplifier module consists of a Nd:YAG zig-zag slab side-pumped by a 30mm x 1.2mm LD array at 807nm (HAMAMATSU) on each side. Each LD array operates at a peak power of 900W for a duration of 0.200ms at 50Hz (duty 1%) synchronized with the oscillator. The LD arrays were placed to the slab and the output was directly coupled into the slab without any coupling optics.The extraction efficiency increased about two times with birefringence compensation especially at higher small signal gain values which well coincided with a Frantz-Nodvik model calculation. A maximum extraction efficiency of upto 73% for the laser mode volume was obtained at the small signal gain of 3.36 with M squared of 1.2.

A higher-average power laser-amplifier system with high efficiency and high beam quality has been constructed using a water-cooled 1064-nm Nd:YAG slab laser amplifier of 6mm x 9mm x 126mm pumped by two 1.2 kW Q-CW LD arrays (HAMAMATSU) of 1cm x 6cm at 1kHz (duty20%), collimated by six 2-mm diameter rod lenses. A maximum average output of 68W (extraction efficiency of 61% for the laser mode volume, optical to optical conversion efficiency of 14%) at 1kHz was obtained at the small signal gain of 3.03 with a good beam pattern using the 90 degree quartz rotator to compensate for the thermal birefringence. After reducing the wavelengh chirping of 1.2kW Q-CW LD arrays, we can achieve a maximum average output power of 100W with an extraction efficiency of 71%.

The successful operation of these systems shows that it may be scalable to the design of a higher average power laser system of over 1kW with high efficiency and high beam quality.

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Passively Q-switched single-frequency Nd:YAG ring laser with feedback and phase conjugation

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Stable beat-free Q-switched lasing was obtained in several arangements of the ring resonator with optical feedback. A novel design of the single-frequency Nd:YAG oscillator capable of producing up to 200 mJ at 10 Hz in the near diffraction limited beam was developed. Computer modelling of the laser operation is presented.

Q-switched Nd:YAG lasers delivering narrow-bandwidth pump beams are imperative for efficient and reliable operation of diverse devices based on nonlinear optical conversion, such as harmonic generators, optical parametric oscillators etc. At present injection seeding is considered to be the most advanced method to produce single-frequency oscillation in Q-switched solid-state lasers [1]. However the injection seeded systems are comparatively complicate as they virtually employ two lasers: a low power, frequency-stabilized, narrow-bandwidth oscillator and a regenerative amplifier. Alternative optical schemes based on the ring resonator arrangement, being much simpler, suffer from relatively low pulse energy, usually 10...20 mJ. Besides to our knowledge no data have been reported so far with respect to pulse-to-pulse energy/shape stability in solid-state ring lasers with feedback [2, 3].

In our research we have studied a number of ring laser configurations with optical feedback.. As an example Fig.2 shows experimental arrangement capable of delivering 60- mJ, 15-ns-single-axial mode pulses at 1-10 repetition rate. The important feature of ring lasers with the feedback, as was revealed in the experiment, is that unidirectional lasing can be sustained within a substantial change of feedback coupling. Yet 4% feedback was enough for stable lasing of ripple-free pulses (Fig.1b-d).

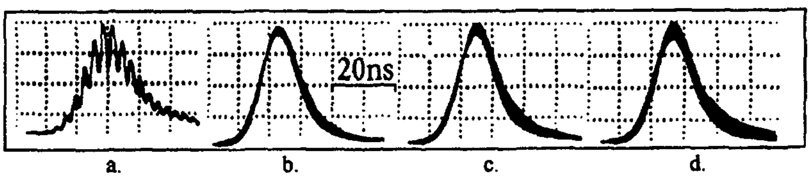

Fig.1. Oscilloscope traces of the recorded laser pulses.
With no feedback: single pulse (a), with feedback: 160 pulses superimposed (b), 320 pulses superimposed (c), 640 pulses superimposed (d). Scale 10 ns/div.

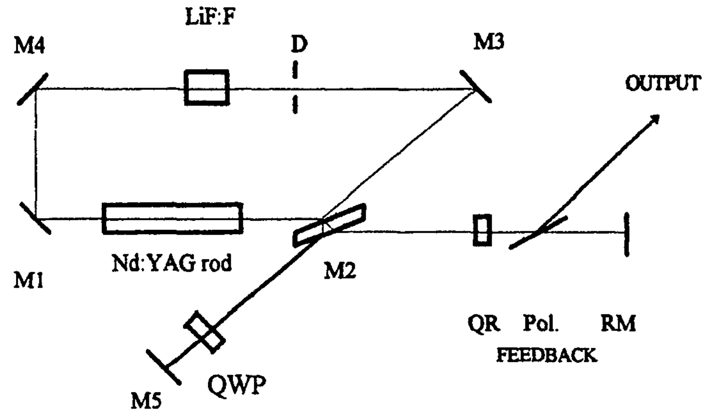

Fig.2. Nd:YAG ring laser with optical feedback.
The four-mirror cavity consists of HR mirrors M1, M3, M4, and LR mirror M2 placed at the Brewster angle. Retromirror RM provides clockwise generation. 90^0 quartz rotator QR and the polarizer serve for outcoupling the radiation backreflected by HR mirror M5.

Lower than 4% feedback resulted in more often mode beats in the output pulses. We found experimental arrangements for which the modulation was less than 5% for 99% of pulses with pulse-to-pulse energy stability within +/-5% for thousands of shots. The effect of sustaining single-frequency lasing by a high transmission mirror, serving as the feedback , extends opportunities of pulsed Nd:YAG ring lasers. In particular additional energy extraction was obtained in the scheme which incorporated glass etalon (both surfaces being uncoated) as the feedback, phase conjugation mirror positioned behind the etalon, and Faraday rotator serving for rejection of the laser pulse from the ring resonator. The oscillator based on this design produced single-frequency, near diffraction limited radiation with energy up to 200 mJ in a12-ns pulse at 10 Hz.

The computer model, in which rate equations for passive Q-switching and transient effects in the phase-conjugator were used, adequately describes the experimental results.

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Laser and Spectroscopic Parameters of Cr^{4+}-Doped Laser Crystals

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Summary

The demonstration of laser operation of chromium-doped forsterite ($Cr:Mg_2SiO_4$) has led to interest in other Cr_{4+}-doped crystals suitable for laser operation in the 1.2 - 1.6 mm wavelength region. In our research, we have focused on crystals of olivine structure analog to forsterite since these crystals are among the few materials that exhibit strong Cr^{4+} luminescence. Tunable laser operation of cunyite ($Cr_{4+}:Ca_2GeO_4$) was first demonstrated in 1996 with potential tunability in the 1.3 - 1.6-micrometer range. Recently an all-solid-state continuous-wave cunyite laser was reported that utilized a 1-W MOPA semiconductor diode device as the pump source. In this presentation, we will review the laser characterisics of Double Clad Fiber Laser (DCFL)-pumped cunyite $Cr:Ca_2GeO_4$, and Ti:sapphire-pumped $Cr^{4+}:LiScGeO_4$ olivine, a new Cr^{4+}-based laser crystal, with a potential for 800-nm laser diode pumping. The pump source used to pump cunyite was a 9W SDL CW Fiber Laser (SDL-FL10-3911). There are several features that make the fiber laser an attractive source of pump light for a cunyite laser system; the emission wavelength of 1107-nm is overlapped by the broad absorption bands of cunyite, the fiber laser output is near-diffraction limited enabling a tight focus of the pump radiation in the gain crystal, and the fiber laser is more compact, efficient and robust than the large frame neodymium lasers previously used to pump Cr^{4+}-ion activated lasers. The Cr^{4+} laser resonator consisted of a standard four mirror Z-fold cavity symmetric about the laser crystal and 80 cm in length. The calculated cavity waist size (w0) inside the gain rod was 40 mm. To achieve a good match between pump spot size and cavity mode size a 10-cm focal length lens was used to focus the pump beam to a spot of 30-mm radius. Thermoelectric cooling of the laser crystal was implemented reducing the operating temperature of the active region to -10 °C. Nitrogen gas was used to purge the crystal facets to prevent condensation. A SF10 glass prism was inserted for tuning purposes into one arm of the laser cavity. The Cunyite crystal absorbed 95 % of the pump radiation and was cut for light propagation along the crystal a-axis and polarization parallel to the b-axis. The crystal facets were polished flat/flat and antireflection coated for the laser wavelength. The folding angle of the cavity arms was kept small to avoid asymmetry in the cavity focus

inside the Cunyite rod. The laser operated at 1410 nm without a tuning element inserted in the cavity and a maximum output power of 210 mW was observed for a pump power of 3 W utilizing a 5% output coupler. With the tuning prism inserted in the cavity the observed thresholds for laser operation were 0.69 W and 1.7 W for 2 and 5 % output coupling respectively at the peak of the gain. Slope efficiencies of 6 and 17 % were measured for 2 and 5 % output couplings respectively. The tuning range of 1375-1500 nm was measured for the fiber-pumped Cunyite laser utilizing a 2 % output coupler.

The Cr^{4+}:$LiScGeO_4$ crystals used in laser experiments were grown by the flux method. The absorption spectra of Cr^{4+}:$LiScGeO_4$ were attributed exclusively to the transitions of the Cr^{4+} ion. The absorption band peaks at 800 nm for light polarized parallel to the b-axis which means that laser diodes may be used for efficient end-pumping of Cr^{4+}:$LiScGeO_4$ laser. The room temperature emission spectrum of Cr^{4+}:$LiScGeO_4$ shows only one band with a maximum at 1100 nm which is attributed solely to Cr4+. The room temperature fluorescence lifetime of Cr^{4+} in $LiScGeO_4$ for 800-nm excitation has been measured to be 7.5 microseconds. In our laser investigations of Cr^{4+}:$LiScGeO_4$ the pump source was a free-running gain-switched Ti3+:Al2O3 pumped by a Q-switched, frequency-doubled Nd:YAG laser with a repetition rate of 10 Hz. The resonator consisted of two 30-cm radius of curvature mirrors coated for the 1200-1350-nm spectral region separated by 13 cm. The 3-mm long Cr^{4+}:$LiScGeO_4$ crystal was polished flat/flat with antireflection coatings on both faces and positioned at the center of the cavity. A maximum pump pulse energy of ~8 mJ was measured in a 11-ns pulse-width at 795 nm. Using a 25-cm focal length lens to focus the pump beam a spot size of ~400 mm was generated inside the gain medium. Laser operation was observed for absorbed pump energies higher than the threshold of 1.5 mJ when 2 % output coupler was used. Maximum slope efficiency of 3% was measured for the 10-% output coupler. Maximum output pulse energy of 0.1 mJ was measured for absorbed pump energy of 6 mJ. With the inclusion of a birefringent plate in the cavity the Cr^{4+}:$LiScGeO_4$ laser was tuned from 1220--1380 nm.

In conclusion, an all-solid-state fiber-laser-pumped Cr:Ca_2GeO_4 laser system was demonstrated. Tunability over the 1375-1500-nm spectral range has been demonstrated. Cr^{4+}:Ca_2GeO_4 represents a new tunable solid-state laser material based on the Cr^{4+} ion with the potential tuning range extending from 1300 nm to beyond 1500 nm in the near infrared spectral region. This spectral range may cover both the 1.3 and 1.55 micrometer wavelengths which are important for optical communications as well as the eye-safe wavelength range beyond 1.45 micrometer. Pulsed laser operation of $LiScGeO_4$ laser was also demonstrated over the 1220-1380-nm range. The development of other new potential Cr^{4+}-based materials and their applications will also be discussed.

The research is supported in part by NASA/IRA, NYS HEAT program, NYSTFF, ARO, and AFOSR.

MONOLITHIC SOLID-STATE RING LASERS WITH POLARIZATION-FREQUENCY SPLITTING OF THE OPPOSITELY DIRECTED LIGHT WAVES AND WITH POLARIZATIONALLY ISOTROPIC RESONATORS

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Theoretical and experimental investigations were made of finding of the conditions of creation of monolithic solid-state ring lasers with polarizationally aniso- and isotropic resonators taking into account the geometry of nonplanar resonator, the active medium refraction index and polarization characteristics of total internal reflectors and dielectric mirror.

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In recent years intensive investigations were made of the utilization of strong competition of the oppositely directed light waves (ODLW) in the solid-state ring lasers (SSRL) with a homogeneously broadened gain line for obtainment of highly stable unidirectional single-frequency lasing in the SSRL with monolithic nonplanar ring resonators (MNRR) and laser pumping.

Much more complicated task is the elimination of the ODLW strong competition for obtainment the stable bidirectional lasing in the monolihic SSRL with the aim of employment of such SSRL for the registration of nonreciprocal optical effects, because it is not possible to insert into the monolithic SSRL additional elements (e. g. , crystal for second harmonic generation, rapidly-relaxing nonlinear absorber or nonreciprocal amplitude Faraday element), permitting to stabilize the bidirectional lasing in the nonmonolithic (sectional) SSRL [1].

In this work theoretical and experimental investigations were made of practically single way to control the lasing regimes in the monolithic SSRL - the changing of the ODLW coupling, polarizations and frequencies by choice of the MNRR geometry, refraction index, polarization properties of resonator reflectors (naturally, at the account of the possibility of applying external magnetic field on the monolithic SSRL).

Taking into account the complexity and labour requirements of manufacturing of monolithic SSRL, in given work the characteristics of such SSRL were investigated, first of all, for the case of the simplest example of symmetric MNRR in the form of the skew rhombus with four reflecting surfaces - minimally possible number of reflecting surfaces

for MNRR. Created for the present time monolithic SSRL have just such MNRR, thus on three surfaces (sides of polyhedron of the active medium) there is a total internal reflection, and on the forth side – dielectric mirror ensuring a low reflection coefficient ($\leq 20\,\%$) at the pump wavelength of semiconductor laser ($\lambda \approx 0.807\ \mu m$) and a high reflection coefficient ($\geq 99\%$) at the SSRL emission wavelength ($\lambda_1 \approx 1.064\ \mu m$ and $\lambda_2 \approx 1.318\ \mu m$).

The polarization-frequency characteristics of the MNRR were calculated with the help of the Jones matrix method under accounting the rotation of the ODLW polarization planes: as "geometric" - due to rotation of laser beam under round trip of the MNRR and "physical" - due to appearance of the phase difference between the p- and s-polarized waves under total internal reflection from three plane surfaces of the MNRR and reflection from the output multilayer dielectric mirror coating on the spherical surface of the MNRR. The geometric rotation is determined by angles of binormals turns to the planes of insidence. The "physical" rotation depends on angles of insidence and refraction index n of the polyhedron from active medium (for solid-state active media $n \sim 1.38 - 2.2$).

The conditions for obtainment of summary polarization plane rotation angles $\alpha_\Sigma \approx \approx \pi/2$ or $\alpha_\Sigma \approx \pi$ were found. When $\alpha_\Sigma = \pi/2$ the MNRR eigenmodes have orthogonal circular polarizations and frequencies shifted to the half of the intermode space (c/2L). When $\alpha_\Sigma = \pi$ the MNRR are polarizationally isotropic and this is very important for obtainment a nonpolarized laser radiation and for investigations of anisotropic properties of active media. It was established that in the symmetric MNRR the degree of polarization-frequency decoupling of the ODLW is increased under increase in value of refraction index. The restrictions on refraction index can be diminished in the monolithic SSRL with asymmetric MNRR.

The results of theoretical investigations were in good agreement with experimental investigations of $YAG:Nd^{3+}$ monolithic SSRL with effective laser pumping since at small pump powers ($P \leq 100$ mW) the thermally induced anisotropy in the active medium is very small and the degree of depolarization of the SSRL radiation is also slight ($\leq 10^{-3}$).

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NONRECIPROCAL OPTICAL EFFECTS IN THE SOLID-STATE RING LASERS WITH SELF-PUMPING WAVES CREATED BY USING ACOUSTOOPTIC FEEDBACKS

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Experimental and theoretical investigations were made of nonreciprocal optical effects in the rotating CW YAG:Nd^{3+} solid-state ring lasers with stabilization of bidirectional lasing by self-pumping waves created by using stationary and nonstationary acoustooptic feedbacks.

NONRECIPROCAL OPTICAL EFFECTS IN THE SOLID-STATE RING LASERS WITH SELF-PUMPING WAVES CREATED BY USING ACOUSTOOPTIC FEEDBACKS

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Very efficient method - the method of self-pumping waves (SPW) was proposed by us in [1] for suppressing the competition between the oppositely directed light waves (ODLW) and for stabilizing the beat regime in the rotating solid-state ring lasers (SSRL) with homogeneously broadened gain line. This method ensures identical values of the gains and losses for the ODLW due to self-diffraction both the ODLW and SPW on the interference population-inversion gratings induced in the active medium. The SPW are formed from part of the ODLW radiation coupled out of the ring resonator and then directed back to the active medium at small angles to the resonator axis ($\alpha_{SPW \to ODLW} \approx 0$ or $\approx \pi$).

It was found that the effectiveness of the SPW method increases sharply in the mode-locking regimes due to a reduction in the coupling between the ODLW because of spatial-temporal decoupling of OD ultrashort pulses (USP) in the active medium.

Various acoustooptic (AO) feedback circuits were proposed by us in [2,3] for creation of the SP USP when the rays diffracted by AO modulator (AOM) are returned to AOM and then, after secondary diffraction, to the active medium. It should be noted that after ten years our works are repeated by Hanna D.C. with colleagues from University of Southhampton, UK (see, e. g. [4]) without any references to our articles.

In this work the experimental and theoretical investigations were made of the influence of such SP USP, of the laser parameters, and the nonreciprocal acoustooptical effects on the amplitude-frequency characteristics of the YAG:Nd^{3+} SSRL. A number of non-trivial experimentally discovered effects has been interpreted and analysed theoretically.

It was established that the creation of the SP USP in the AO mode-locking regimes with AO feedbacks is a very effective method, since it makes it possible to achieve

simultaneous stabilization of parameters of the USP as well as the ODLW intensities and ODLW frequency difference ν_B in the rotating SSRL.

It should be stressed that the most stable beat regime in the rotating SSRL was achieved when bidirectional lasing was stabilized by only one SPW created by using quasiresonant AO feedback, which was realized by returning one of the diffracted rays to the AOM by reflectors performing quasiphase conjugation on rotation of the ray image by 180^0. It prevented the appearance of a system of coupled optical resonators which, first, greatly increases the sensitivity of SSRL to various perturbations and, second, strongly affects on the ring resonator eigenfrequencies for the ODLW. Such effects were observed in SSRL with the antiresonant AO feedback which was created in SSRL with a resonator axis self-intersecting in the AOM at an angle close to twice the Bragg angle.

The further stabilization of the beat regime in the SSRL was achieved by using the SP USP created by a time-dependent quasiresonant AO feedback permitting to obtain SP USP with a Doppler-modulated $\Delta\nu_D$ optical frequency. It was found that time-dependent self-diffraction of the OD and SP USP by interference population-inversion gratings give rise to new nonreciprocal optical effects: light-induced constant $\nu_B^{=}$ and alternating-sign $\nu_B^{\sim}$ ODLW frequency difference or can stabilize the beat regime in the SSRL. This, as experiment shows, depends on the parameters of SP USP optical frequency modulation. For example, light-induced alternating-sign nonreciprocal effects were observed at low modulation frequences of a reflector in AO feedback ($f_M \sim 10^2$ Hz, $\Delta\nu_D \leq 100$ kHz). The stabilization of the beat regime was observed at frequencies $f_M \sim \omega\eta/Q \sim 1$ MHz, close to the rate of establishment of the field in the laser resonator.

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Lasing in Crystal Fibers.

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Different laser sources are needed now to use in a optical fiber communications. For some applications it is possible to use successfully diode lasers. However these sources have the known limitations. Among them it is the frequency stability of the laser emission, thermal characteristics, mechanical properties etc. Moreover the difficulties sometimes are arised at the coupling the laser diode emission to the single-mode optical fiber.

The application of the crystal fibers enable us to use all the positive properties of the crystal hosts(high stability of the mechanical parameters, high quantum yield of the luminescence, the big set of the possible dopants and promising laser transitions in rare-earth ions etc.) together with the specific properties of the common optical fibers.

The crystal fibers used in the experiments were grown by the method of laser heating minipedestal growth (LPHG) in oxidizing atmosphere. We chose yttrium-aluminum garnet doped with the rare-earth and transition ions as a model crystal host due to it's well-known mechanical, crystal growth and spectral properties. We carried out the experiments for the determination the birefringence in the crystal fibers and for the comparison of these data with the same of the bulk material. Our results shows that the crystal fibers possesses the higher value of the mechanical stresses then the bulk crystals and the aftergrowth annealing could improve the situation very rare. However the distribution of the stresses over the cross-section of the crystal fiber is homogeneous enough due to the small diameter of the sample (300 - 600 μm). Mechanical stresses could strongly effect on the lasing characteristics of the fibers doped for instance with Cr^{4+} ions and considerably less under the doping by the TR^{3+} ions.

Lasing experiments we carried out with the use of the Nd:YAG fibers with diameter of 400 - 500 μm. As the pumping source we used both the single laser diodes with the pumping power of 1 W and the pigtailed laser diodes set with the output of 4 W. the example of the input/output characteristic of this laser (the rod with 500 μm diameter) is shown in Fig.1. The relatively low total efficiency (about 12%) is determined by the uncoated faces of the rod and the thermal effects in the active medium. The effect of the polishing quality of the rod faces and the roughness of the barrel of the rod could be seen more brightly then for the common bulk rod.

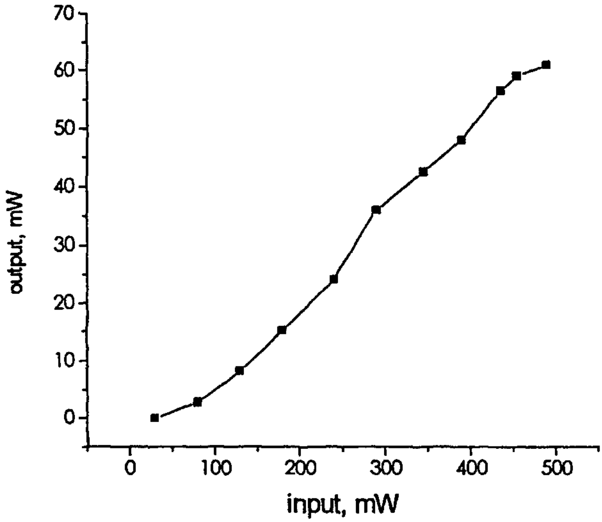

Fig.1. Lasing properties of the Nd:YAG crystal fiber laser with the 500 μm diameter under the pumping by the 1 W laser diode.

In our experiments we demonstrated the efficient laser operation of the crystal fiber lasers with the end pumping by the laser diodes and pigtailed laser diode sets. We have shown the influence of the heat deposition in the active medium and the importance of the right cooling of the rod. It was estimated the influence of the roughness of the rod barrel and mechanical stresses in the fiber on the lasing parameters.

Nd:YLF-Nd:YAG High peak and average powerlaser system with SBS pulse compression.

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For a lot of applications, such as technology, generation of x-ray radiation for lithography, diagnostics of plasma with use Thompson scattering lasers with the subnanosecond pulses, repetition rate more than several hertz and pulse energy several Joules are required. The nonlinear processes, among which most important are optical damage and self-focusing, limit the use of direct amplification approach for the creation of such lasers. For effective suppression of these processes the application of lasers with pulse compression is perspective. In such lasers rather long laser pulses are generated and amplified, and their compres sion are carried out at a final stage. For producing subnanosecond laser pulses the use for the compression by effect SBS is the most convenient due to high energy efficiency and symplicity. In the given work the pulsed-periodic solid-state laser using the given approach for providing short subnanosecond of short pulses is described

The laser system consists of several basic units. The master oscillator on a crystal Nd: YLF generated single transverse and longitudinal modes pulse by duration 3 ns FWHM with energy 0.5 mJ. Further this pulse was amplified in multipass preamplifier on Nd:YLF rod 10 mm diameter 80 mm long, then it was divided into two parts by splitter, one of which was compressed in the SBS-compressor on a basis CCl4 up to 150-200 ps, and second was reflected from a mirror without change of the duration. Thus on an output preamplifier, through which second time passed radiation, was available two pulses, necessary for further compression in the basic SBS-compressor operated as the amplifier. After that these pulses of various

duration (0.15 and 2.5 ns) were amplified in multypass zigzag amplifier on a plate from the phosphate Nd:glass by the size 6x40x300 mm up to energy several J and then were transformed to the second harmonic in a crystal KDP. On an output of the system there was SBS-amplifier on a basis gaseous Ar where the energy was converted over the long pulse into short one with high energy efficiency.

For calculation of parameters of laser system numerical model, allowing to simulate amplification of a pulse in laser system in view of nonlinear effects, frequency conversion to the second harmonic of pulsed-periodic radiation and SBScompression of a pulse, was developed. In the report the detailed characteristics of described laser system will be given and comparison of calculated and real parameters of radiation will be made.

RAPID GROWTH OF LARGE KDP and DKDP CRYSTALS (55-57 cm) FOR LASER FUSION APPLICATIONS

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Large KDP crystals with sizes up to 450 mm had been grown previously incrystallizers with a volume of 1000 L at growth rates of up to 10-20 mm/day. First measurements of optical quality (depolarization loss, light absorption, wave front distortion and damage threshold) [1] showed that, in general, large rapidly grown crystals can be as good as small crystals grown both by the traditional or rapid techniques [2].

In this paper we report the recent results on rapid growth of KDP and DKDP (90% deuterated) crystals of up to 57x57 cm2 in crossection and upto 55 cm in height. Crystals were grown by the temperature reduction method starting from a saturation point 65-75¦C to room temperature and lower, down to 8-10¦C. This progress was made possible due to the scientific and technical research performed to understand the problems connected with scaling the growth process. The effect of different factors, such as impurities, stress, growth rate and regeneration conditions, have been investigated for the case of large crystals. The design of the 1000 L crystallizer, as well as the design of the platform-crystal holder have been modified to provide the conditions required for the growth of 250 kg crystals. All growth tanks were equipped with constant filtration systems, specially designed for operating at

the high supersaturations needed for fast growth. It has been proven that the constant filtration was one of the important conditions required for obtaining crystals of high damage threshold and optical uniformity.

37x37 cm2 and 41x41 cm2 single crystal plates have been cut from the grown crystals for optical measurements and use on Beamlet, the NIF prototype, currently operating at LLNL.This work was performed under the auspices of the U.S.Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-ENG-48.

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LASER METHODS
IN MEDICINE

Laser Therapy of the Disfunctions of Eye Accommodation and Sensory Systems

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New ophthalmologic methods using low-energy laser radiation are considered. The methods are effective for treatment of such eye diseases connected with accommodation and sensory systems disfunctions as progressing myopia, nystagmus, amblyopia, eyesight fatigue.

New ophthalmologic tools that employ low-energy lasers have been developed in Russia last years. These were the result of efforts made mainly at Moscow Helmholtz Research Institute for Eye Diseases. Numerous experimental and clinical investigations have opened new possibilities of differential diagnostics and treatment of the sensory and optical systems of the diseased eye. Progressing short sight (myopia) is among eye faults that can be treated most effectively with ophthalmologic tools using low-energy lasers. Long static strain of the ciliary muscle of the eye followed by the accommodation spasm is the main cause of myopia. The new method allows the treatment and prevention of progressing myopia and involves the improvement of the ciliary muscle functions by transscleral acting on it with the light of a low-intensity infrared laser. The similar methods have been developed also for treating nystagmus, strabismus, amblyopia, and eyesight fatigue.

Beside transscleral laser stimulation, the methods that use laser interference patterns for treating eyesight faults have been developed. These methods are used also for improving the ciliary muscle functions and increasing the resolving capability of the sensory system of the eye. Regardless the state of the optic system (ametropia, corneal opacity, cataract, narrow or dislocated pupil), both random (speckles) and regular (generated by holographic optical elements) interference patterns produce distinct retinal images, which improves the frequency-contrast performance of the eye and trains its image-forming abilities. The method allows a distinct moving («live») image to be generated on the retina without a patient's awareness, which is very helpful in treating children who suffer from amblyopia. The special ophthalmologic «Laser glasses» and «Speckle imager» have been made for treating disfunctions of eye accommodation and sensory systems. The instruments were tested and approved by the Ministry of Public Health of the Russian Federation for clinic use. Now they are used in many clinics and medical institutions all over Russia. These unique ophthalmologic tools have already

helped many thousands of people the majority of which are children with progressing myopia. «Laser glasses» were tested in the field conditions – aboard the aircraft carrier during a long voyage. The device proved highly effective for correction of eye accommodation malfunctions and easing eyesight strain of flying staff. Exposures used in the methods are several orders less than permissible values. This makes the laser therapeutic methods applicable for treating eyesight faults of children and people with increased radiation sensitivity. Novel laser technologies effectively complete conventional methods of treating of eye diseases.

INSTRUMENTAL AND TECHNICAL PROBLEMS IN PHOTODYNAMIC AND INTERSTITIAL THERMOTHERAPY

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Methods of photodynamic (PDT) and intratissue or interstitial thermotherapy (ITT) are new and developing precision technologies in laser medicine. These technologies having much in common are predominantly used in oncology.

An acting parameter in these both approaches is a power density within the range 0,2-1 W/cm^2 which provides an adequate energy density in tissues. However, intratissue effects turn to be different. For PDT it is the markedness of photodynamic reactions damaging the tumour. For ITT it is the maintenance of a stable isotherm ≈ 44°C in the tumour and in the surrounding healthy tissue. A common technological peculiarity for both methods is a delivery of the irradiation to the tissue with even volumetric density. Such evenness is provided with spherical and cylindrical diffusers at the end of the light guide. However, the unit volume of the even irradiation of the diffuser is limited and does not exceed 0,5-1 cm^3. Thus, the partial consecutive way of tumour volume irradiation is inevitable. An important moment is the quality of dispersion at the diffuser itself. To perform this procedure better, more control is needed.

Methodologically, PDT procedure is more technological and simple; some overdose is allowed. ITT has to provide isothermal heating of tissues (t = 45°C) within the whole tumour volume. A stable temperature has to be maintained within the whole procedure. An objective control is possible, of course, with MR tomography. In more simplified variants it is possible to use contact thermodetectors, inserted into the irradiated tissue.

Several years ago we have developed a universal unit for the application in PDT on dye-laser with copper-vapour laser pumping. 12 laser units "Yachroma-2" have been manufactured. Currently, new compact units have been developed. They are based on gold vapour and copper vapour lasers («Yachroma-M»), and also on Nd:YAG lasers. Corporation "PRIBOR" manufactures laser apparatuses "Lason" to be used for ITT. There are two variants of this unit - based on Nd:YAG (λ = 1,06 μm) and on semiconductor laser diodes (λ = 0,9 μm).

OPTICAL MONITORING OF LYMPH FLOW IN MICROVESSELS

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For some diseases dynamic parameters of blood and lymph flow in microvessels are changed. These parameters contain an important diagnostic information about the state of the organ (or tissue) under interest. In this paper experimental investigations of statistical characteristics of lymph flow have been carried out with the help of speckle-interferometry using focused laser beams. Momentary power spectra of scattered intensity fluctuations obtained have been analyzed. Spatial velocity distribution in vessel cross section has been investigated. Temporal dynamics of lymph flow parameters has been discussed. Attempt of reconstruction of lymph flow dynamic parameters from the light scattering characteristics has been made. Estimation of light pressure and thermal effects induced by focused laser irradiation of lymphocytes investigated has been performed.

Lymph flow in microvessels is non-stationary and randomly changed in time [1,2]. By now the existed methods of determination of motion parameters of these flows [3-5] have not completely developed . They are, in most, of qualitative character. In this paper the lymph flow has been considered from the viewpoint of nonlinear dynamics.

Experimental set-up used the experiment is similar to the one described in [2]. PC was applied for data processing instead of spectrum analyzer used in previous experiments. Using the experimental set-up the momentary power spectra of scattered intensity fluctuations have been obtained. Connection of scattering characteristics of lymph flow with cinematic parameters of lymph motion has been demonstrated in this paper. The analysis both of quick and slow temporal changes in lymph flow dynamics has been done. Video recording of lymph motion in microvessel has been simultaneously performed with speckle-interferometric investigations of the same lymph vessel for visual control of optical measurements mentioned.

The reasons causing both the spatial inhomogeneity and temporal non stationarity of lymph motion are discussed. It has been considered the examples of regulatory mechanisms action of microcirculatory system under the conditions of laser beam irradiation of lymph microvessel.

Attempt of solution of reverse problem, namely: reconstruction of lymph flow cinematic parameters from the light scattering characteristics has been made.

Speckle-interferometric method using focused laser beam may be effectively applied for investigation both of dynamic parameters of spatially non-uniform bioflows and their temporal dynamics. In addition, the method allows to evaluate the relative changes of lymph flow velocity in the vessels both of human and animal microcirculatory systems.

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LASER REFRACTOMETRY OF BIOLOGICAL MEDIA

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Diagnostic methods come to the determination of one or another physical parameter: absorption, transmission, dispersion, spectrum etc.. Among them optical refractive index is very informative. Any change in the medium results in refractive index change. Different processes can be obtained by measuring the refractive index. The question is only the sensitivity and the time of measuring (fast-action).

Refractometry is a classical technique. The sensitivity of traditional measuring is usually 10^{-4}-10^{-7}. That's no bad. But time of measuring is few seconds or tens of seconds up to tens of minutes. That's very slowly, as during the measurement the investigated medium can change the properties. Moreover traditional methods need transparent media. But biological media have an absorption and dispersion.

We have developed new Intracavity Laser Refracometry in Reflection (ILRR) method which is perspective for biological media investigations. Our method is based on the control of the laser spectrum. The main element of the experimental set-up is a probing two-mode standing wave laser with a three- mirror bent cavity. Two mirrors and a prism of total internal reflection (TIR) are used as reflectors of the cavity. Oblique reflection from a boundary between media gives rise to a phase difference Δ between orthogonal polarized light waves. Therefore, the equidistant spectrum of longitudinal modes is split into two spectra that correspond to natural oscillations with orthogonal polarizations. The frequency separation between split modes is equal to

$$\nu_{12} = (c/2L)(\Delta/\pi),$$

where **c** is the speed of light and L is the cavity length. If the angle of incidence and the material of TIR prism are constant and known, the value of beat-frequencies depends only on refractive index of medium, which contacts with prism. This is an idea of ILRR method which allows to determine refractive index in the vicinity of the prism surface, as in case of total internal reflection the light penetrate into external medium on several wavelengths. With the help of ILRR method absolute values and the changes of refractive index **n** can be measured.

We have used compact diagnostic system (L=30 sm.) based on two-mode He-Ne 633 nm laser which is more convenient to biological investigations. The sensitivity of measuring depends on stability of beat-frequencies in laser. The best result we have achieved in experimental laboratory is equal to **dn**=10^{-9} (ninth figure after point). Time

of measuring depends on inertness of laser cavity and interaction between generated modes. In our case it is equal to several microseconds.

ILRR method was used for determination of absolute refractive index values of healthy and sick persons. It is obtained that the refractive index values are more for healthy persons than for sick ones. This difference is 10^{-3} approximately. It can be explained by inflammatory process which reduces plasma density.

Refractive index behaviour during the treatment of diphtheria was investigated since the moment of the reception to the hospital. The refractive index values correlate with the course of the disease. The most complicated course of the disease is during the first and the second weeks. Recovery takes place on the third week. By that time refractive index value is restored.

We have investigated photoresponse of the blood to laser irradiation in vitro. In medical treatment of various diseases blood is often used as an object of laser irradiation. Without knowing the photoresponse process in real time it is difficult to determine optimum therapeutic dose and understand the mechanism of laser treatment. Photoresponse (decrease of refractive index up to 10^{-4}) starts just after the turning on He-Ne therapeutic laser. After several dozens milliseconds there is a saturation. Weak thermal effect produces small and slow influence on the refractive index behaviour. It can be supposed that fast part of the photoresponse corresponds to the start of biochemical processes. The investigations of photoresponse of plasma, leukocytes and erythrocytes showed that the erythrocytes are main photoreceptors of red light. The refractive index behaviour in real time allows to evaluate maximum therapeutic dose. It is equal to 10^{-9} J for one erythrocyte.

The refractive index behaviour of the blood of white mice under He-Ne laser irradiation during 1,5 hour was investigated in vivo. The nature of this behaviour allows to divide the irradiation into stimulating and depressing parts. The maximum therapeutic dose was also evaluated in vivo. It is equal to $2\text{-}3{\cdot}10^{-9}$ J for one erythrocyte that is close to the value obtained in vitro.

ABLATION OF BIOLOGIC TISSUES USING ULTRAVIOLET LASERS: IMPACT OF FLUENCE, REPETITION RATE AND ENVIRONMENT

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Pulsed ultraviolet lasers operating at various waves lengths are capable of precise tissue ablation with minimal damage to adjacent tissue. Ablation thresholds are different at each wavelength and vary as a function of the optical properties of the tissue. Before developing clinical systems, careful evaluation of ablation thresholds, optimal ablation fluences, delivery systems, repetition rates and environments are necessary at each wavelength. Our laboratory has conducted several investigations to apply UV lasers for various medical purposes. In order to apply these lasers for clinical use, we have developed a standardized methodology for optimizing laser parameters.

The methodology to evaluate laser tissue interactions is highly varied and not standardized in the literature. Our group performs a systematic evaluation using the following methodology. Using high magnification optics we record the laser tissue interaction using flash photography with time synchronization. We determine the minimum ablation threshold using the high magnification technique which allows us to identify very thin layers of ablation in tissue. Alternatively, we take a large number of samples and record the number of pulses required to perforate a sample of known thickness. From this data, we can also extract the depth of ablation per pulse. For both techniques we vary the medium, air, water, or other fluids to study the impact of the environment on the ablation process. These basic techniques yield a great deal of information about the physical events which accompany the ablation process. The high magnification allows us to identify the products of ablation including gas bubbles, particulate matter and shockwaves. In order to account for biologic variability, we use multiple tissue samples and repeat the process many times.

It is critical to determine the beam profiles whether we use free beam or fiberoptic delivery systems. Small changes in energy density lead to major changes in ablation depths particularly at the shorter wavelengths. Beam profiling is performed using a Cohu camera and Big Sky software. Laser wavelengths studied include 378, 355, 351, 308, 266, 248, and 193nm.

In order to examine differences in tissue damage, all tissues are submitted for histologic analysis. The tissue is stained with various agents including hematoxalyn and eosin, Mason's trichrome, and van Geisson's stains. We use both standard light and polarized light microscopy for analysis. More recently, we have developed a standardized

methodology using digital imaging of the microscopic slides. This technology allows us to quantify thermal and shock wave damage zones. Thus, comparison of the tissue effects becomes more quantifiable.

We also employ thermal cameras to look at the surface temperatures during the ablation process. Needle thermocouples are inserted to measure temperatures adjacent to the ablation zones. These readings are then compared to the results of the histologic analysis. Thermal analysis gives only part of the picture since damage from the shockwaves can be quite substantial. To analyze the time course and magnitude of the shockwaves, we use calibrated PDVF transducers.

Data from a variety of studies in myocardium, bone, and eye tissue will be presented. In each of these cases, choosing the appropriate fluences, delivery systems and environment plays a major role in optimizing precise ablation with minimal adjacent injury.

Ho: YAG (2.1μm) and Nd:YAG (1.44μm) Bile Duct Stone Pulsed Laser Lithotripsy

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Pulsed laser lithotripsy is one of most promising invasive method for intracorporeal, safe, and rapid bile duct stones removal. Clinical application of this technique is to fragment and thus remove the calculi lodged in the common bile duct and pancreatic ducts, particularly those inaccessible to any other method.

A pulsed lasers as Ruby laser, Q-switched or free running Nd:YAG (1.064μm) and Cr:YSGG laser, pulsed Coumarine or Rhodamine 6G dye lasers, Ti:sapphire, and Q-switched Alexandrite laser operating in visible spectral region had been used for the stone fragmentation till now.

The wavelength used, the laser pulse duration, the energy of the pulse, and the pulse repetition rate are main parameters which determine the quality and the rate of stones disintegration. These parameters, together with a protection of the stone surrounding tissue against an intensive laser radiation, guarantee an operative, safe, and rapid intracorporeal stones removal.

Microsecond pulses has been proved to be best for fragmentation at visible wavelength with the energy up to 140mJ per pulse and repetition rate 5Hz - 10Hz for this spectral region but the fragmentation efficiency quite differs for different stones. The efficiency of the laser fragmentation depends on the stone composition and the laser radiation wavelength. This is why the efficiency of the fragmentation differs for the different lasers.

A small sensitivity of the stone fragmentation to the optical wavelength is expected for fare infrared optical region because of high absorption of stones in this region. So the long wavelength solid state lasers are seemed to be very perspective in this field.

We will present study of the NIR laser radiation interaction with biliary stones. A high power free-running solid-state Ho:YAG (2.1μm) [3] and Nd:YAG (1.44μm) lasers with up to 500mJ/pulse output energy at up to 3Hz had been used as an efficient laser sources for bile-duct stones fragmentation. Cholesterol stones, mixed stones, and pigment stones has been fragmented in vitro.

A systematic experimental study of the influence of the laser systems parameters on the fragmentation process will be presented. The results obtained with Ho:YAG and Nd:YAG (1.44μm) lasers will be compared.

A specific question of the laser lithotripsy is protection of the surrounding tissue against an intensive laser radiation. Although a few histological evidence of scarring or obstruction at the various stone fragmentation processes and at fiber sites have been observed till know, the protection of the surrounding tissue from a laser damage is the first-rate task.

We studied the Ho:YAG laser radiation interaction with a tissue to determine under what conditions the laser pulses does not create damage of the tissue cells. Such of results are important for the stone-tissue recognition system design. New, intelligent automatic stone-tissue recognition system for the laser lithotripsy in clinical use will be presented. The system is applicable for different types of lasers.

MOLECULAR MECHANISMS OF STIMULATING LASER IRRADIATION

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At present time Low Power Laser Irradiation (LPLI) has been used in clinics in two different aspects:

1. at tumor photodynamic therapy (PhDT) and
2. at laser therapy of the majority inflammatory diseases

The tumor cells injury at the PhDT is mediated by free radical reactions initiated with exogenous photosensitizes. The proposed mechanisms of stimulatory actions of LPLI are mainly speculative and have very poor experimental evidence. In addition they are unable properly interpreted the beneficial effects of laser therapy

Improvement of micro-circulation is the most illustrative and well proved (both experimentally and in clinics) pathophysiological effects of LPLI action, partly regulated by blood leukocytes.

In our previous communications we have proposed the hypothesis on free radical mechanisms of stimulatory actions of LPLI The main points of this hypothesis are as follows:

1. Target cells for LPLI action are represented by blood leukocytes, and endogenous porphyrines act as chromaphor of laser irradiation in the red part of the spectrum. Porphyrin level both in cell membranes an blood plasma can be increased in different pathological states and under action of 5-aminolevulenic acid.
2. The porphyrins can initiate free radical reactions after absorption of laser photons that induced increase ionic permeability of leukocyte membranes including for calcium ions. The growth of calcium content in cytosol of leukocytes brings in to action the calcium-depending processes including leukocyte priming. One

manifestation of this can be the activation of so-called «inducible NO-synthase» in blood leukocytes

3. NO-synthase formed in leukocytes produces $NO^{\cdot}$, precursor of Endothelium Derived Relaxing Factor (EDRF). This EDRF give rise to microvessels vasodilatation, decrease of leukocyte adhesion and aggregation. All these are typical of observed beneficial clinical effects of laser therapy

The report offers and discusses experimental data that can be considered as the proof for the possibility of photosensitize priming of leukocytes, that can be the base for the curing effect of laser therapy.

THE EXPERIENCE OF LOW-ENERGY LASER THERAPY TREATMENT

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The main purpose of our study was to show the possibility of low-energy laser use for a wide range of diseases treatment as the result of the experience, gained by the specialists of our Centre.

We rely upon a very rich practical experience of our own in the use of low-energy He-Ne laser in such fields of medicine as: cardiology, pulmology, gastroenterology, neurology. We've treated 257 patients, suffering from miocardial ischemia of different functional classes. It was stated, that clinical effect is achieved with the use of the following preparations: nitrates, B-blockators, Ca-antagonists. A traditionally adopted medicamental method of treatment is often accompanied by side effects and in 60% of cases it is characterised by resistance to drug effect.

The use of laser radiation of 1,5 mW power with 633 nm wavelength for intravenous procedures in case of miocardial ischemia treatment, makes it possible to bring down the dosage of medicamental therapy and to provide the prolongation of remission period.

The results of the investigations showed the positive therapeutic effect in 90% of cases with patients suffering from angina pectoris functional class 2, and in 63% of cases - angina pectoris functional class 3.

The positive effect of laser treatment was accompanied by the prolongation of the remission period in cases of all the patients. We have also obtained the data, demonstrating the biostimulating effects of laser therapy, namely, the structural and functional change of a cell membranes which take place via the higher activity of the antioxidant cell membrane system.

Regarding angina pectoris to be intermediate step in prethrombosis status, we did our best to discover the best ways of intravascular hyperthrombosis treatment.

Using He-Ne low-energy laser radiation we've proved that laser therapy is a positive independent method in treating variant angina patients with complications of cronical blood hypercoagulability.

Intravenous laser therapy use laser radiation of 1,5 mW power from very first days of pneumonia treatment makes it possible to solve the problem of alveolo-capillary blockage and to improve the process of histologic recovery in the zone of inflammation.

There were treated 356 patients suffering from different types of bronchopulmonary symptoms, among them there was 156 patients with acute pneumonia. In the result in 96,5% of these cases we found out clinical-histological recovery. Clinical effect consisted of rapid normalisation of temperature, leucocythosis,

normalisation of plasma protein and according to X-ray examination - normalisation of natural structure of pulmonary tissue with no signs of pneumophibrosis.

The use of low-energy laser therapy for treating different forms of bronchial asthma resulted in the positive effect in 78% of cases for the atopical type and in 67% of cases for infectional ones including the hormonal dependent. On the whole there treated 276 patients.

We also tried the method of low-energy laser therapy for treating peptic ulser. With the use of this method we have treated 875 patients who suffered from gastric ulser and duodental ulcer. In 98% of all those cases after the treatment carried out with the help of laser, scarring was noticed by 10-14 days since the start of treatment. The prolongation of remission period was also evident.

**Laser Doppler Microscopy of Blood Flow:
State-of-the-Art, Potential Applications, and New Approaches**

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During the last 25 years since the first laser Doppler microscopes (LDM) were designed different probing and detection schemes were tested for noninvasive measurements of directed blood flow velocities in single tubes and capillaries both *in vitro* and *in vivo*. Conventionally measurements are performed in vessels with inner diameters ranging from 50 to 150 μm with LDM based on cw He-Ne lasers and using forward-scattering detection mode.

Nonetheless to study a large number of problems related to fundamental understanding of blood rheology *in situ* and to biomedical and clinical applications further progress in quantitative measurements and monitoring of blood flows in a wider range of vessel sizes and optical properties of surrounding media is needed. These problems include:

- assessment of the role of RBC interaction (deformation, aggregation, correleted orientation, etc.) on flow geometry, velocity and concentration profiles;
- effect on blood rheology of drag reducing agents, microcapsulated drugs, blood substitutes, photocensitizers, and other substances administered into blood;
- effect on blood rheology of external factors (electric and magnetic fields, light, ultrasound, etc.) therapeutically applied intra- or extracorporally;
- effect on blood flow of hypoxia, hypo- and hyperthermia, and other physical conditions applied to blood and/or to tissues surrounding the vessel.

To study these and other problems the LDM should enable highly localized measurements of velocities under nonstationary flow conditions in

vessels with diameters up to 300 μm, imbedded into highly scattering tissue (skin, tumor, etc.).

This paper will focuss on the discussion of different approaches that can potentially enable such measurements. They include:

- application of cw and time-gating techniques with different scheme arrangements;
- application of long- and short-coherence length lasers and leds;
- Monte-Carlo simulation of the LDM signal in different regimes.

DIFRACTION OF A FOCUSED SPATIALLY-MODULATED LASER BEAM BY A RANDOM PHASE OBJECT

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Illuminating spatially modulated laser beams are the laser beams with a regular interference pattern. In Ref.1 we described cases when fringe spacing in the illuminating laser beam considerably exceeds object inhomogeneities sizes. The interference fringes of average intensity with contrast depending on statistical parameters l_ϕ, σ_ϕ are formed in the scattered speckle-modulated field. In this paper we consider a new technique based on diffraction of *focused* spatially-modulated laser beam on random phase object and analysis of the speckle field interference in diffraction zone (Fig.1). Diffraction of speckle field behind the random phase object acquires a qualitatively new nature if the object is placed in the area of focusing of a spatially modulated laser beam. The dependence of dynamic field average intensity fringes contrast on the object parameters has been established.

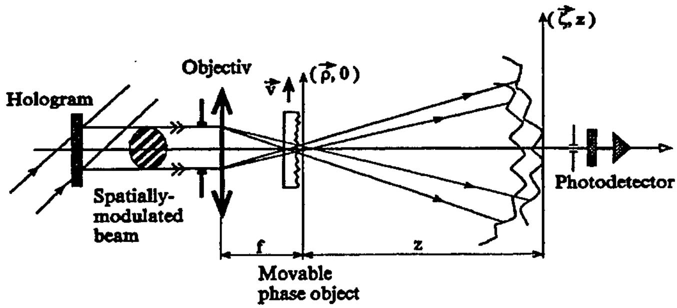

Fig.1. Scheme for interference fringes recording diffraction field induced by the focused spatially modulated laser beam scattering by a moving random phase object.

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LIMITS OF LOCALIZING THERMAL PHOTOCOAGULATION

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There are a number of biophysical and physiological factors which influence the size, nature and degree of clinical photocoagulation. Since the primary interaction mechanism for laser pulses of durations ranging from microseconds to many seconds is thermal, and from nanoseconds to microseconds might be thermo-acoustic, it is worthwhile to consider how the dimensions of photocoagulated tissue could be best controlled through a better understanding of the nature of thermal damage of subcellular structures and thermal denaturation of proteins. It is well accepted that heat conduction plays a key role in the redistribution of energy not only during the laser exposure, but also following the exposure, and the duration that each cell is located in either the irradiated area or adjacent area of elevated temperature is critical (Barnes, 1974; Hu and Barnes, 1970; Priebe and Welch, 1978; Ham, 1987; Sliney and Wolbarsht, 1980; Sliney, 1982). This is termed the "time-temperature history," and the thermochemical denaturation of proteins depends not only upon the peak temperature, but the entire duration (of many milliseconds or seconds) that the temperature is elevated. Therefore, the geometry of the tissue exposure will influence the resulting lesion. Probably the most extensive series of fundamental studies relate to retinal photocoagulation, where lesion size and the scaling of photocoagulation threshold has been shown to vary in much the same way regardless of the pulsed exposure duration (Courant et al., 1989; Sliney and Wolbarsht, 1980). Whether laser energy was delivered in nanoseconds or seconds, the spot size dependence of retinal (apparently thermochemical) damage scaled as 1/(spot size) for spot sizes up to 1-2 mm. This can only be explained by the impact of heat flow. This analysis permits us to analyze the values and disadvantages of selecting different pulse durations to achieve a given result. The idea of delivering energy in a brief pulse to cause localized damage within microseconds has been a proposal for decades, and even given a special name (Anderson and Parrish, 1983), however, evidence that this is possible can still be questioned. Studies of threshold injury in minimal retinal images show that even minimal lesions are larger than the optical image and this is interpreted as a result of heat flow.

The only retinal lesions which have been shown to be sharply defined and dependent only upon the light distribution on the retina result from either ultrashort or photochemical damage mechanisms and these will not be discussed here. It is also known from theoretical models that blood-flow, a competition between photochemical and thermal effects and even eye movements affect the zone of retinal damage when exposures last for seconds, and these effects will not be considered. Current retinal photocoagulation is normally limited to durations of 0.5 s and shorter.

Thermal injury of biological tissue has been studied for many decades with important studies dating at least from those of Henriques (1947), who studied skin injury by observational, histological and theoretical methods. His group clearly showed that thermal injury is strongly dependent upon heat conduction from the irradiated tissue. In more recent decades many of the careful scientific studies of localized thermal injury and thermochemical rate processes for proteins have resulted from studies of laser photocoagulation, where the thermal energy can be carefully applied by a well defined radiant exposure. Hu and Barnes (1970) studied the critical temperatures as a function of time (i.e., the thermochemical rate process) for protein denaturation and enzyme inactivation by irradiating different proteins and enzymes with a CO-2 laser, adding to the earlier, basic studies on proteins and enzymes of Wood (1956).

Mathematical models of thermal retinal injury have been quite successful in predicting thresholds for ophthalmoscopically visible retinal lesions for single-exposure conditions for a large variety of retinal image sizes for exposure durations varying between less than a millisecond to many seconds. The Arrhenius function for thermal denaturation of proteins shows the importance of time-temperature history (Allen and Polhamus, 1977; Mainster et al., 1970). Much of the injury occurring from pulsed exposures actually occurs during the cool-off time when local tissue remains elevated; hence, the retinal image-sized dependence of injury (Sliney and Wolbarsht, 1980). However, to date, these mathematical models with currently used rate-process coefficients have not been successful in predicting the N-0.25 thermal additivity rule for small image sizes (Sliney and Marshall, 1991). This requires further study.

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LASERS IN SURGERY AND ONCOLOGY

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Special properties of «laser scalpel» (asepticity, ablasticity, hemostasis, moderate postoperative pain, thin zone of coagulative necrosis which leads to faster wound healing) have led to its wider use in practical surgery of supurative wounds, burns, gastrointestinal diseases and others.

Possibility to deliver laser light via optical fiber through the endoscope directly to the inner organ allowed the use of lasers in endoscopic surgery: for treatment of gastric ulcer and gastrointestinal bleeding; for endoscopic polipectomy; for lytotripsy in choledecholythiasis and nephrolytiasis; for recanalisation of esophagus, cardia and rectum in tumoral stenosis; for laser photodestruction of prostate tumors; for laser conisation in cancer of cervix uteri and others.

The use of lasers led to a real breakthrough in oncodermatology. The use of lasers sufficiently simplified the operations for both benign and malignant skin tumors, including the most aggressive and malignant neoplasm – melanoma. Laser surgery can be successfully applied to patients with skin malignancies in out-patient clinics. Both therapeutic and cosmetic results appear better after laser surgery than after traditional techniques – «knife» dissection and gammatherapy.

In the last 6 years in the State Research Center for Laser Medicine 1641 patients with squamous-cell, basal-cell and metatypic skin carcinoma (total - 2610 tumors) were treated. In 112 patients (140 tumors) Laser Dissection (LD), in 1281 patients (1573 tumors) Laser Photodestruction (LPD) and in 174 patients (897 tumors) Photodynamic Therapy (PDT) have been performed.

LPD was performed in patients with tumors from 1.0 to 1.5 cm and with superficial tumors of body and extremities up to 5.0 cm in diameter. Laser wounds healed under the crust. Tumor recurrence was found out in 22 patients (1.7%) during 2.5 to 8 months.

LD was performed in patients with primary skin tumors from 1.0 to 5.0 cm in diameter. Laser wounds were sutured or closed with a free skin flap. Tumor recurrence was found in 3 patients (2.5%).

PDT was performed in patients with multiple, large (from 10 to 260 cm^2), recurrent, residual tumors and in cases of «inconvenient» localizations of tumors in the face. The treatment had effect in 99.4% of tumors (total resorption in 81.9% and partial resorption in 17.5% of tumors). Follow-up from 2 months to 4 years revealed recurrences in 14 (17%) patients with multiple and extensive tumors. These solitary small

recurrent tumors were evaporated with CO_2-laser.

PDT is a new technology in medicine, which currently has a number of confirmed and doubtless evidences of its advantages comparing to traditional approaches in treating skin cancer. World experience shows that PDT is effective for the treatment of skin cancer and some other localizations; however, skin phototoxicity after the application of the most widespread photosensitizers and light regime limitations which have to be observed by patients within 3 - 6 weeks force oncologists to restrict indications to this method in oncodermatology.

In our opinion, LPD is the most proper approach in case of small (up to 1,0-1,5cm), solitary, not numerous skin cancers.

In 1988-94 surgical treatment of skin melanoma was performed in 211 cases: traditional «knife» wide dissection in 121 patient (group A), 90 patients underwent operations with use of CO_2-laser (group B).

We used 3 techniques for CO_2-laser treatment of skin melanomas:

1) in 8 cases of suspicious foci without morphological proof biopsy was carried out followed with immediate laser photodestruction of melanoma (LPD);

2) in 71 cases laser dissection was performed with primary suturing or, in 22 of them, laser wound was closed with a free skin flap (LD);

3) in 11 patients laser dissection was used with wound healing under the crust.

The best immediate results were achieved in patients treated with LD with primary suturing. During the follow-up from 1 to 6 years tumor recurrences were revealed in 9 (7.4%) cases in group A and in 1 case in group B (1.1%). Metastases in lymphatic nodes and distant organs were revealed in 37.2% in group A and in 25.6% in group B; 72.5% of patients survived 3-year period in group A and 81% in group B.

In recent years we also successfully used PDT for treatment of primary pigmentless and pigmented melanomas and intradermal melanoma metastases. First follow-up data obtained within 1 - 4 years are now being evaluated.

Laser irradiation of the blood in therapy of children granuloma annulare: a pilot study.

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A new therapeutic modality using low-intensive transcutaneous He-Ne laser irradiation of the blood has been developed for treatment granuloma annulare in children. A good clinical effect has been achieved in 9 of 11 patients.

Granuloma annulare (GA) is a benign dermatosis of unknown etiology. It can start at any age but is more common in children and young adults. GA appears as a smooth, firm papules or nodules which may be erythematous or skin-colored. It presents as solitary or multiple circular lesions. It's number is of 1 to 100 and more, and is divided into six clinical types: localized, generalized, perforating, subcutaneous, linear and papular. Histologically at the level of the subpapillary plexus of the blood vessels, or deeper, are single or multiple foci of granulomatous inflammation.

Vasculitis is one of the main suspected mechanisms of GA's pathogenesis (2;4). Blood vessels in affected areas show endothelial swelling and thickened walls that may be so marked as to cause occlusion. Immunoglobulins, complement, and fibrinogen have been observed in blood vessel walls by direct immunofluorescence. It is known the positive effect of laser irradiation on the microcurculation (1;3). The purpose of our study was to assess the therapeutic efficacy of transcutaneous He-Ne laser irradiation of the blood (TLIB) in patients with GA.

Eleven children with GA aged 2.5 to 14 years (6 girls and 5 boys) with disease standing of 1month to 4 years were treated. Localized form of the disease was diagnosed in 5 patients, in the rest 6 ones the process was with foci on the upper and lower extremities. All patients were previously ineffectively treated with various drug. Blood was irradiated by He-Ne laser at the wavelength of 632.8 nm using a special attachment

applied to the cubital vein projection (5), power at the lightguide tip 20 to 25 mW, exposure for 15 to 25 min, 10 sessions per course. The courses were repeated after 2-4 weeks. Two children were administered a single course of TLIB, 6 received two courses and 3 received three courses. TLIB was the only treatment modality.

Clinical remission (with negligible secondary pigmentation developing at the site of previous foci) was attained in 5 patients, in 4 an appreciable improvement was observed, consisting in a marked decrease of infiltration and erythema. In 2 patients with generalized GA the treatment was ineffective. Repeated courses of TLIB improved the treatment efficacy. No side effects were observed in the course of therapy.

Hence, the first results of our research have shown high efficacy of transcutaneous He-Ne laser irradition of the blood as the monotherapy in patients with GA. Further studies of this treatment are needed.

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The influence of laser irradiation on photobleaching of endogenous and exogenous fluorochroms and blood oxygen saturation in biological tissues in vivo. The relation to the photodynamic and low intensity therapy.

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ABSTRACT

The present paper deals with the observation of fluorescence and absorption spectra of biological tissues in vivo during laser irradiation. The absorption spectra of tissues in the visible wavelength range supply one with the blood oxygen saturation value while fluorescent spectra give information about photobleaching. The CW laser irradiation with wavelengths 630 and 670nm with power densities from 10 to 1000 mW/cm^2 has been applied. The relation of the observed effects to the photodynamic therapy and low intensity therapy is discussed.

INTRODUCTION

The influence of laser irradiation on biological tissues in vivo may induce different effects depending mainly on parameters of laser light (wavelength, power density, pulse duration etc.) and chromophors in tissues absorbing this light. Figure 1 demonstrates the effects induced by light absorption in tissues and corresponding applications of lasers in medicine.

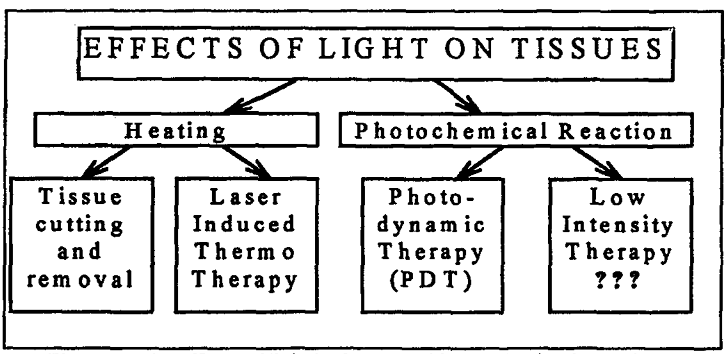

Figure 1. The effects of light in tissues and its application in medicine

This paper deals with investigations of photochemical reaction in tissues due to the presence in it of endogenous and exogenous photosensitizers and their relation to PDT and low intensity laser therapy.

MATERIALS AND METHODS

For the measurements of absorption and fluorescent spectra of tissues during laser irradiation we applied the fiber optic spectrometer. The light from light source (halogen lamp and laser) was delivered to the tissue by means of quart fibers. For the in vivo measurements these fibers were at the same side of tissue and we measured the diffuse reflected light. After passing through the tissues the diffuse reflected (from halogen source) and fluorescent light (excited by the laser) has been collected by the receiving fiber. The output end of the receiving fiber was the input slit of the spectrometer. To avoid interference of diffuse reflected and fluorescence light we used special band pass filters. The blood oxygen saturation and relative hemoglobin concentration is calculated from the absorption spectra in real time and time dependence is displayed at the computer screen. The fluorescence exited by the laser (627.8 or 670 nm) is observed in the 650-900 or 700-900 nm spectral range. We used diode laser (670nm) and gold vapor laser (627.8 nm) at power densities from 10 till 1000 mW/cm^2.

RESULTS AND DISCUSION

It was clearly observed that autofluorescence of tissues is decreased under the influence of laser irradiation when the power density of incident light exceeds the 100 mW/cm^2. The time behavior of tissue autofluorescence dependencies with different laser power densities is analyzed. We assume that tissue autofluorescence with excitation in the red wavelength range is due to the presence of endogenous porphyrins. So the bleaching rate may serve as a controlling parameter during laser therapy. We also observed the increase in blood oxygen saturation in the microcircular vessels under the influence of laser irradiation. However these changes has been observed only when the laser irradiation power substantially exceeded that of typically applied for low intensity therapy.

With the use of exogenous photosensitizers applied for photodynamic therapy (sulphanated aluminum phtalocyanine, ALA induced PPIX) we observed their photobleaching in tissues during laser irradiation. The fluorescence intensity of the above mentioned photosensitizers with concentrations in tissues typically used for PDT (1-5 μg/cm^3) is much higher than tissue autofluorescence. We also observed the decrease in blood oxygen saturation during laser irradiation as a result of enhanced oxygen consumption during PDT and vessel destruction.

Comparing the results obtained for endogenous and exogenous fluorochroms in tissues the hypothesis about possibility of low intensity therapy mechanism as PDT with endogenous photosensitizers is discussed.

PROTECTIVE EFFECTS OF SOFT-LASER BIOSTIMULATION IN AN EXPERIMENTAL MODEL OF GLOMERULOSCLEROSIS AND INTERSTITIAL FIBROSIS

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Background: Low power laser irradiation (wavelength 300-1100 nm) has been reported to have a variety of effects on in vitro and in vivo neural tissue including: neurite elongation [Mulligan et al., 1991], neuritic outgrowth from olfactory neuroepithelial explants [Mester and Snow, 1990], Schwann cell proliferation [Van Breugel et al., 1991], astrocyte division [Yew et al., 1990], changes in striatal monamines and amino acids [Shen, 1982], and changes in the response of neurons to trauma to the peripheral [Rochkind et al., 1987 and 1988] or central nervous system [Schwartz et al., 1987; Assia et al.,1989; Rochkind et al., 1989; Anders et al., 1993]. During the past few years, we have investigated the effects of low power laser (633nm) biostimulation on the glomerulosclerosis.

Materials and methods: Adriamycin, a commonly used antineoplastic, induces glomerular lesions in rats, resulting in persistent proteinuria and glomerulosclerosis. The effect of volume on the progression of adriamicyn-induced nephropaty was studied in 53 male Wistar rats (120-140 g) observed for 30 weeks and separated into 3 groups: healthy control group (HCG, n=8) inoculated i.v. with 1 ml of saline, and nephrotic groups inoculated i.v. with a single dose of Adriamycin of 3 mg/kg body weight. The nephrotic rats were separated into 2 groups: nephrotic control group (NCG) receiving only Adriamycin, and laser irradiated nephrotic group (LNG) treated with percutaneous blood laser biostimulation.

Results: The 30-weeks survival rates the LNG (100%) and HCG (100%) were significantly higher than those of the NCG (83%). The proteinuria observed in the HCG (range 6,16+-0,4 to 10,1+-1,14 mg/24h) was significantly lower than that observed for all the nephrotic groups throughout the experiment. The LNG also presented significantly less proteinuria (range 9,03+-0,2 to 16,11+-1,28 mg/24h) than NCG (45,4+-6,51 to 254,7+-22,76 mg/24h) from week 10 on. The mean frequency of damaged glomeruli was 0,2+-0,08% for HCG, 44,1+-12,6% for NCG and 10,4+-3,2% for LNG. The median value of the tubulointerstial lesion, evaluated by a semiquantitative method, was zero HCG, 10 in NCG and 3,5 in LNG ($p<0.05$) for all groups compared to HCG).

Conclusion: The data indicate that percutaneous blood laser biostimulation has a protective effect on adriamicyn-induced nephropaty.

IN VIVO LASER FLUORESCENCE SPECTROSCOPY IN THE HUMAN SKIN EXAMINATION

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Reflectance and fluorescence spectroscopy are successfully used for skin diseases diagnostics. Human skin optical parameters are defined by its turbid, scattering properties with non-uniform absorption and fluorescence chromophores distribution, its mult ilayered structure, and variability under different physiological and pathological conditions. Theoretical modeling of light propagation in skin could improve the understanding of these conditions and may be useful in the interpretation of in vivo reflectance an autofluorescence spectra.

The methods available for testing the efficacy of topical sunscreens have improved considerably in recent years. Nevertheless, so far no simple and rapid test has been proposed to measure in vivo transmission spectra of sunscreens in the UVA region.

In present work the temporal behavior of in vivo reflectance and autofluorescence spectra of human skin under UV irradiation (4 MED) and external mechanical pressure were investigated. Experimental results and Monte Carlo modeling of light distribution in skin were compared and demonstrate good agreements. Combination of diffuse reflectance and autofluorescence measurements is very promising technique for precise erythema and pigmentation of the human skin evaluation. Simple model of the skin tissue was used for analysis of blood concentration in different skin layers. In vivo autofluorescence measurements are suggested to improve and precise detection of blood content (i.e. erythema evaluation) in human skin. Spectral changes that occur after sunscreen application were measured with a fluorescence spectrometer (LS 50B, Perkin Elmer, UK) equipped with a Y-shape quartz guide for in vivo measurements. Five sunscreens with different protection factors in the UVA range were tested. The excitation-emission maps of human collagen, skin, and sunscreens were analyzed. As a consequence of the human skin and sunscreen's fluorescence map analysis, the optimal spectral regions (both for direct and indirect fluorescence measurements) were detected. In vivo fluorescence and remittance spectroscopy were used to investigate the time dependence in transmission spectra of epidermis with applied sunscreens. We also evaluate the feasibility of in vivo fluorescence measurements for the investigation the sunscreen's water-resistance. The procedure is simple, and values obtained can be used to predict UVA protection on the basis of the mathematical algorithms.

TMLR with 3 different lasers: An in vitro and in vivo study.

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Short- and long-term tissue effects, pressure and ablation efficiency of pig myocardium was evaluated after Er:YAG, Ho:YAG and CO_2 laser impact.

Transmyocardial laser revascularization is a technique for treating ischemic heart disease. With the availability of high power lasers, it has become possible to perforate a beating heart. It is speculated that the laser drilled channel may stay open and/or support or stimulate in the long-term the growth of new vessels that link to the existing circulation. As a result the ischemic myocardium could either be supplied by oxygen rich blood directly from the left ventricular cavity or by reconnection to existing vasculature. Preclinical and clinical results so far are promising. With respect to histology after laser revascularization, observations however are still controversial. The reason is that the mechanism of action of this procedure remains largely undefined. It is not clear for instance, whether the beneficial effects of the procedure are due to newly established channels or to subsidary adaptation, elicited by the thermal, oxidative or mechanical components of the injury. Furthermore, since the mechanisms are unclear it is even unclear which kind laser source is best suited for a safe and successful treatment.

The goal of this study was to investigate and to compare the basic mechanisms of laser radiation of different wavelengths and different application systems. In order to visualize and to determine characteristics of the ablation process, the ablation rate, the laser-induced pressure during ablation and the extent of the laser-generated tissue-damage as a function of laser energy and delivery system were measured. Supplementary measurements in water and polyacrylamide gel contribute to a better understanding of the underlying physical processes. Additionally, in vivo experiments were performed to assess the extent of thermal and mechanical alterations and the geometry of the laser channels after six weeks.

The different dynamics and shapes of the laser-induced channels reflect the difference in the optical penetration depth of the three wavelengths used. In the case of the Er:YAG and the CO_2 laser, the radiation is absorbed in a thin disc (1/e depth of 4 μm and 12 μm, respectively) leading to an explosive vaporization and the formation of a moving ablation front. The cylindrically shaped channel grows in length as laser radiation is continuously deposited through the growing vapor cavity since water vapor is much less absorbing than liquid water in the infrared. In contrast, the Ho:YAG radiation is spread over a more cylindrical volume (1/e depth of 330 μm). As a consequence, a large almost spherical vapor bubble is formed. The largest bubble was generated with Ho:YAG radiation and the lens fiber.

In addition to the images taken to measure the size and the shape of the laser-induced channel, a needle hydrophone was used to document the presence of any laser-induced pressure transient during or after the ablation process. The strong pressure transients in combination with the fast expanding channel especially in the case of the Ho:YAG laser seem to have the potential to mechanically damage tissue by tearing the myocardium.

The histological evaluation of the in vitro as well as in vivo samples reflect these findings. Whereas the geometry of the channel produced in the myocardium with the CO_2 and the Er:YAG laser mirrors the geometry of the laser beam and the fiber size, respectively, the channel found after Ho:YAG laser impact was found to be much larger along the myofibriles than across. Besides the tissue tearing, the extent of the thermally damaged tissue adjacent to the laser channel was found to be much larger in the direction along the myofibriles (¦) than in the direction across the myofibriles (⊥) for all laser sources and delivery systems used (see Table I).

Laser	thermal damage	pressure	scar formation	angiogenesis
Er:YAG	¦ 57±79 μm	+9/-8 bar	¦ 0.8±0.6 mm	-
	⊥ 65±34 μm		⊥ 0.6±0.4 mm	
Ho:YAG bare-fiber	¦ 419±112 μm	+30/-14 bar	¦ 2.5±0.7 mm	+
	⊥ 237±90 μm		⊥ 1.5±0.5 mm	
Ho:YAG lens-fiber	¦ 714±60 μm	+55/-30 bar	¦ 1.7±0.8 mm	+
	⊥ 335±189 μm		⊥ 1.0±0.4 mm	
CO_2	¦ 650±100 μm	< 0.2 bar	¦ 2.3±0.4 mm	+
	⊥ 250±80 μm		⊥ 1.8±0.5 mm	

Table I: Summary of the results obtained in this study

The histological evaluation after six weeks of the in vivo experiments showed scar formation along the whole length of all the transmyocardial channels. The scar however was relatively inhomogeneous and sometimes not well delimited against the myocardium. Within the scar tissue different degrees of neoangiogenesis were observed. The most important finding of the in vivo study however was that no remaining endocardial connection of the channel to the cavity of the left ventricle was found.

In conclusion, the primary finding of this study is that the myocardium can be perforated with all laser sources within less than 10 pulses. It could be shown that different tissue effects are generated, caused by the difference in the absorption coefficient. Further studies have to be performed to show whether the extent of thermal damage and/or laser induced mechanical tissue tearing has a positive or negative influence on the clinical outcome of the transmyocardial laser revascularization procedure.

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